THE CORRIDOR OF LIFE

TRICERATOPS

A dinosaur with three horns and a great neck-plate of bone. The skull is six feet long and the whole animal was about twenty-five feet long

THE CORRIDOR OF LIFE

by

W. E. SWINTON

TRICERATOPS

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The illustration of *Amoeba lescherae* (Fig. 9) is based on a drawing by C. Brown Kelly in the Journal of Microscopical Science, 1944.

FOREWORD

To attempt to describe the life of the past from the various scraps of the fossil forms is curiously like trying to picture the life of a small community from the casual evidences of their apparel. Imagine that very early in the morning we are in an upper corridor of Grand Hotel. As we traverse the silent passage perhaps the only evidence of the various guests is the shoes at the bedroom doors. They are of all sorts and sizes, arranged in all sorts of groupings. Some are neatly set out; some are in series of pairs, some are lonely, and at one door there may be only one tell-tale shoe. Some will be stout but worn shoes, others new and gay, and somebody may have been so forgetful or so ashamed that outside his door there are no shoes at all.

Much could be reconstructed from this evidence; a good deal of it could be assessed with accuracy and there would be many mistakes too. So in these pages I have tried to tell very briefly something about the great historical forms that have walked down the Corridor of Life and have now retired from view. I have tried as best I can to polish most of these shoes, but no doubt occasionally I have replaced them at the wrong doors, as happens even in the best hotels, and some I have probably forgotten to polish at all. For those neglected, wronged, or merely annoyed, I apologize herewith.

I have to record my thanks to Miss Pinner who has furnished all the drawings for the book and to which it owes probably most of its appeal.

I am also indebted to my friends, Dr. Maurice Burton and Dr. A. T. Hopwood, who have read through the proofs of the invertebrate and the mammalian chapters respectively. For all the book's errors and omissions I am alone responsible.

It is possible in these pages to give only the briefest summary of the great field that is outlined, and no mention has purposely been made of the vast and detailed literature upon it which the interested

reader can easily enough find elsewhere. In few periods of the world's history has it seemed more necessary than now that we should get back to the basis of things, to follow the trend of life's progress, and to determine our part in its future direction.

W. E. Swinton

London 1947

THE CORRIDOR OF LIFE

CHAPTER I

INTRODUCTORY

THE purpose of the following pages is to give some simple account of the long history of living things. If conditions under which animals and men and women live had always been the same there would be little need for such a story, and yet thousands of people are quite content to remain ignorant of the fact that change is ever a natural process. For many hundreds of years the description of the creation of the earth and the seas, and the almost immediate colonization of them by a widespread and diversified series of plants, animals and even of man, was generally accepted and the need to examine it closely, or to question it, did not therefore arise. Modern science has innumerable proofs that this simple theory is not literally accurate.

Apart from the interest of its history, it can easily be proved that a study of animal and plant life has great attractions, that constantly there arise strange problems, some of them as yet unsolved, and the student quickly acquires a respect for Nature and a deep appreciation of the beauties and mysteries of the things around us. It is perhaps too often overlooked that in the study of the life of animals, however humble, we are studying some facet of our own complex human life. The very simplest forms of animal life are essentially similar to the minute organisms that constitute some of the cells of our body tissues and the vital carriers of essential foodstuffs in the stream of our blood. The very simplest types of microscopic plants are closely similar to, and sometimes actually are, the cause of diseases that rack the human frame and send epidemics of sickness over great tracts of the earth's surface, affecting thousands of our fellow men and women.

In the pages that follow we shall waste no time in attempting to justify a study of the history of this vague substance and quality that we call life, nor shall we stress that those well versed in its lore can

even turn that knowledge to a profitable end. We shall pursue the story to enjoy the winding paths that we must follow. Our search will take us to many parts of the world and to many a far-distant age. We shall begin with a picture of the earth, so mighty in our eyes, yet, in fact, so insignificant in the immensity of both space and time. What are these things, 'space' and 'time', that fall so glibly from our tongue?

We are faced with the choice that our earth is part of a finite or an infinite universe: that is, it is either part of a great space that is somehow boxed in, but with what outside? or else this star and planet-ridden space, filled with the ether, palpitating with strange vibrations, like light and heat and wireless, that can be trapped and used by those who have the key, goes on for miles and thousands of miles and millions of miles, far into the past, countless aeons before the foundations of our earth were laid, and pressing on into the limitless future, to continue long after the last man will have been forgotten and his successor, whatever that may have been, has disappeared in his turn and left the final habitations to moulder into dust. Time and space, on, ever on, swirling and soaring up and down for eternity.

'Of course,' you will say, 'this is all very romantic and very hard to picture in the mind's eye. We know that the universe is either finite or infinite, and only mathematicians can understand either possibility, but what has it to do with life?' Well, it has this to do with life and with us, that somewhere in that swirling stream of space and time is the little world in which we live. It is much less conspicuous in its background than a ping-pong ball in the middle of the Atlantic. But there it is. Somehow it got created there, at first an uninhabitable and unromantic lump of molten metal and stone. At some time and in some peculiar way the spark of life was kindled and fanned to a feeble flame in this forbidding background. And, directed by some force, that life spread down through the ages with infinite patience and clothed itself in various shapes and hues.

We shall see the waters and in them the inhabitants which had at first no shells or backbones. Then we see the rise of shelled

creatures and later the backboned animals appear, with strange varieties of fish. From the fish came the amphibians, who commenced the real invasion of the land and from whom sprang the reptiles who in their turn produced the birds and the mammals, the latter of which have so far attained their most advanced form in man. So the study, far from being disinterested, is actually a study of our own remote ancestors and the places in which they dwelt.

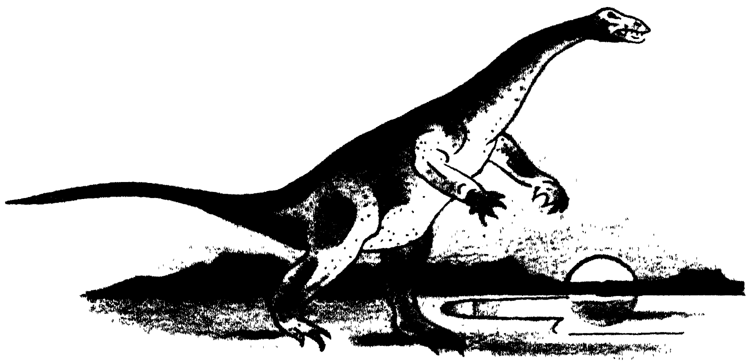
This book is called *The Corridor of Life* for that very reason. It is the story of a visit that we are making together to the ancestral home. We shall see the ancient ruins of the first homestead and follow the dark and dusty corridors of the later mansion, now apparently so decayed but once fresh and gay with youth, though of a different kind from ours. We can peep into rooms and see the relics of long-forgotten relations, some of whom never seem to have 'come to anything' and never left any descendants. Of course, there are other things than ancestors, and we shall see them too, as well as the changes in the family estate itself. We shall meet dark and sunless days with nothing but dull, uninteresting vegetation. We shall see our lands bathed in brilliant sunshine and hear the sound of the bees as they flit among the brilliant flowers; and on some still night we shall watch strange goings-on by the moonlit lake.

It may all seem very strange and improbable but, in so far as we can see, it is very largely true. The records of our family past are not, of course, written in indelible ink on fine parchment that has been perfectly preserved in the mansion's library, but they exist as you shall see; at some future date you may even help to find more of them.

You may not like the story or be proud of the family tree. You may think that you must be descended from a very queer set of relations but there is little you can do about the family past. There it is, and we can only accept it and make the best of it. After all, if we can't do anything about the past maybe we shall be able to do something about the future, though that is another story.

Let us then proceed with the visit and make our way to the family

estate. Fortunately on this journey we can travel quickly and lightly. All the luggage we shall need will be just a little knowledge of the things around us in the world of today and a certain amount of imagination.



PLATEOSAURUS

A dinosaur from the Upper Trias of Germany and France. Length about twenty feet

CHAPTER II

THE EARTH – BACKGROUND TO GEOLOGY

SINCE the earth is the home of life and the only place where life, as we know or can understand it, appears to exist, something must be said about the foundation of our planet and of the major changes that it has seen.

In the early days, although there were many learned men, like Plato, who wondered about these things, they lacked the means for serious investigation and for proving much of their theories. Within the last two hundred years, however, several scientists and philosophers have speculated upon the matter with varying conclusions.

In 1750 Buffon suggested that the solar system might have been formed through the partial breaking up of the sun by collision with another body. Kant, the German philosopher, put forward the theory in 1755 that the earth and the other planets had probably been sorted out by mechanical forces from a vaporous mass, and he conjectured that this mass had been thrown off from the sun's equator by the sheer speed of rotation.

Some years later, in 1796, Laplace, the French astronomer, put a note in one of his treatises also suggesting that the solar system had originated from the sun. This rotating mass of very hot gases was presumed to have been gradually contracting to a smaller diameter and was thus throwing off at its equator, or, rather, leaving behind, lesser masses of similarly rotating gas in the process. He suggested that these lesser and separate masses of gas condensed to form our planets and their satellites.

This theory has several objections. It would seem to demand that the sun, the planets and their satellites should have the same direction and plane of rotation. A major fault of both Kant's and Laplace's theories is shown by recent investigations into the

rotation of the sun, for it is certain that the speed was never so great as to lead to this break up at its equator. Another fault of Laplace's theory is that although it is true of immense bodies of gases it would not be true for smaller bodies such as the solar system where the smaller amounts postulated would merely disperse. Laplace's theory, though inadequate for the formation of our earth, is justified none the less, for it is in this way that stars, not planets, are born.

In the early years of this century two American scientists, Dr. Chamberlain and Dr. Moulton, put forward what is known as the 'Planetesimal Hypothesis'. In this they suggest that the solar system started as a star, but that the gravitational forces, the pull, of this star were disturbed by the passage through space near to it of a larger star.

It should perhaps be explained here that every body exerts a force or pull on every other body. Usually in the objects around us this pull is so small that it has no visible effect, but with the comparatively immense size of the earth and the smallness of these bodies, this power is obvious and the force is called the force of gravity. Thus the cigarette you may be smoking will not visibly be attracted to this book, but both will fall to the ground if they are not adequately supported. In this manner the pull of the larger star in its course so disturbed the gravitational forces of the sun-star that spiral arms of matter were thrown out from the latter. It is suggested that these arms of gas condensed in time to knots of coldish and solid matter and that eventually they decreased in area but attracted to themselves similar pieces of debris. In this way rotating bodies of different size were obtained, starting cold but gradually rising in temperature through the accretion of matter by physical attraction.

The fault of this theory also is that small bodies of gas do not behave in this way.

In 1916 the great English mathematician, Sir James Jeans, put forward what is known as the Tidal Theory. This again suggests that our sun was approached by a much larger star. We all know that the movement of the moon around our earth produces tides

on the waters by its attraction. Similarly, but on an immensely larger scale, tides were produced on the sun by the varying nearness, and consequently varying attraction, of the unknown star. This immense tidal wave of gas reached its maximum as the truant was nearest to the sun and the pull thereafter declined. Thus a vast cigar-shaped body of gas was raised and eventually abstracted from the surface of the sun by this other parent.

From this great body were eventually condensed the planets, and in a similar way their satellites. The theory is substantiated by the relative size and arrangement of our planetary system, as it is now known, culminating with the discovery a few years ago of the postulated but unknown Pluto. Such planets would not be rotating in the plane of the known sun, but in a plane produced by the unknown larger body, and this proves to be the case.

A new theory has just been put forward by Dr. Schmidt of the Soviet Academy of Sciences. In brief, this suggests that the sun passed through one of the meteorite clouds of the Milky Way and captured by its attraction some of the meteorites. In this way were formed the planets revolving around the sun.

Generally speaking, then, we can form a somewhat hazy picture of a time, immensely long ago, far further away than we can possibly comprehend, when our earth was partly liquid and partly gas, and that it very gradually cooled to a somewhat orange-shaped sphere with a heavy metallic centre and a stony exterior. We know nothing about this interior from direct observation, since it lies deeper than we could ever mine, but fragments of meteorites, that are occasionally scattered on the earth's surface from out of space, have provided us with what may be regarded as samples of material very similar to our own earth's deeper layers. The behaviour of earthquake waves also provides valuable evidence, for we know that the shocks and tremors set up by an earthquake can be recorded at places very far away from the scene of the disturbance. These waves are of three kinds and we know that they pass through the deep layers of the earth, through the less deep layers, and through the crust. As the speed and direction of the different waves through the different media can be calculated with con-

siderable precision it is obvious that this testimony is of great importance.

As a result of these methods of investigation it is found that the materials of which the earth is composed vary considerably in their densities. Density may be defined as the ratio between the mass (weight) of an object and its volume (i.e. the amount of space it takes up) and it is commonly calculated by weighing the object and then placing it in a special vessel containing water. The object naturally displaces a certain amount of water which can be measured or drawn off and actually weighed. Simply, therefore, the density of a material or object is usefully given as its weight compared with that of a similar volume of water, and this ratio serves as a handy index of relative weights. This is also known as the specific gravity of the object.

We find, then, that so far as we can see and calculate, the earth is composed of a series of concentric zones of differing complexity. Only the outer of these, the crust or lithosphere, is known to most of us. It is the zone on which we live and walk, on which the mountains are raised and in which the rivers make their beds. We see it in the quarries and in the deepest mines. It is composed of many different kinds of rock, but they all agree in that, if we were to bore through them, sooner or later we should come to great deposits of that material we all know quite well — granite. Actually in many places in the world today the superficial layers of rocks have been worn away and the granite is exposed on the surface. It is calculated that this surface and granitic layer has an average density of 2.7 and that the combined materials form a zone up to 40 miles deep. When we reflect that some of the deepest of the South African gold mines, which are famous for their depths, have only gone down to about 6500 feet, this depth of 40 miles seems enormous, but we must remember that the average diameter of the earth is 7900 miles and that, therefore, this formidable crust, that is deeper than we shall ever be able to descend or exploit, is diagrammatically merely the thin circumference line that we should show if we were to draw a circle of five inches' diameter.

This crust or lithosphere (Greek: *lithos*, stone) floats upon a

substratum of a type of rock known as basalt. This is a dark blue-green or brown rock that is well known to geologists and, in its columnar forms, will be remembered by visitors to the Giant's Causeway or to Fingal's Cave. There is no great mystery as to how some of this deep-seated material came to find its way to the outer world for it escaped through volcanic action long ago. Volcanoes have been well called the 'chimneys in the crust'. Compared with the crustal layer this basaltic zone is approximately the same thickness for it goes down to about seventy-five miles. The average density of the material may be given as 3, but there is evidence that as the layer is traced deeper and deeper it becomes more dense, and to the basalt, rich in silica and magnesium, there is added a certain amount of iron. Below this substratum is a great zone, nearly 700 miles thick and with a density of 3 to 4, known as the Peridotite layer. The name is derived from Peridot, which is the French name, the jeweller's name and the old geological term for Olivine, a mineral rich in silica, magnesium and iron.

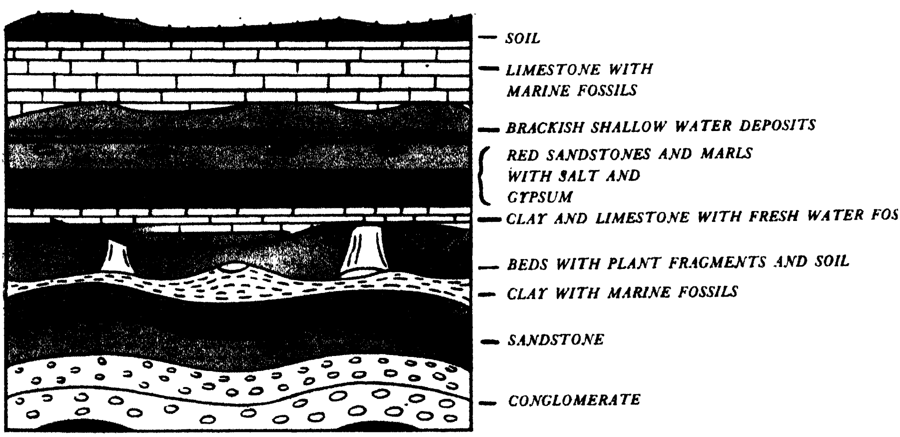


Fig. I DIAGRAM ILLUSTRATING ROCKS AS RECORDS OF GEOLOGICAL HISTORY

This zone may be a mixture of crystals and glassy material and is perhaps similar in composition to the stony meteorites. This comparatively 'weak' zone, together with those already mentioned, is sometimes referred to as the Asthenosphere (Greek: *asthenos*, weak).

Below this again is an enormous zone, nearly 1,000 miles in

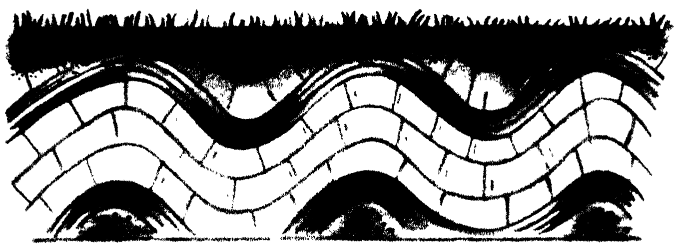


Fig. 2 FOLDED STRATA

thickness, that seems to be composed either of heavy silicates, such as Olivine, with metallic iron, or of metallic sulphides and oxides. Its composition appears to be uncertain from the physical facts, such as the transmission of earthquake shocks, that are available, and because of this at least part of the zone is known as the Transition Zone. Some of the difficulty may be due to the fact that the materials may not be in a form with which we are familiar.

In dealing with these zones we have spoken of depths and materials, but there are two important properties that we have so far omitted to mention — heat and pressure, and the two are obviously interacting. At this point we must pause to consider them.

It is well known to all who have experience of mines and tunnels that it is warmer in these places than on the surface of the ground. Observations made in different parts of the world show that the rate at which temperatures naturally increase in descending shafts, bore-holes and the like, averages 1° F. for every 60 feet of the descent.

This rate works out at an increase of 88° F. for every mile in which we go towards the centre of the earth. On this basis the temperature at 40 miles' depth, that is, at the base of the crust, will be 3520° F., while at the depth we have now reached in our narrative (just about 1800 miles) the temperature must be assumed to be no less than 158,400° F. At the surface the *boiling* point of iron is 4442° F.,

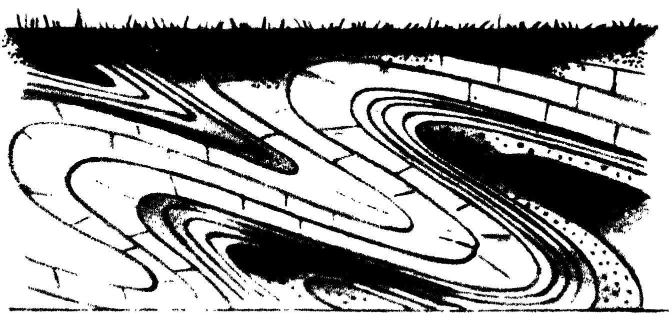


Fig. 3 OVERFOLDED STRATA SHOWING THE OVERTURNING OF SOME BEDS

so what can be happening to the materials in and below the Transition Zone we were considering?

Now, whereas increase of temperature makes most bodies eventually less dense (e.g. water changes into steam, etc.), increase of pressure has the reverse effect. Obviously, as one goes deeper and deeper into the earth, the pressure exerted by the overlying materials, and by the increase of temperature in a confined space, will become very great. Indeed, it can be estimated that at the depth of 1800 miles this pressure will be no less than 18,000,000 pounds per square inch. These facts mean that the materials in this zone, which as we have said probably contain metallic iron, tend to be kept in a non-solid state by the high temperature of the inner earth, yet are held by the tremendous pressure in a state of plasticity. This is even more striking in the innermost zone, a sphere of about 2200 miles' radius, whose centre is the centre of the earth. Here, if our

previous figures are correct, the temperature should be 350,000° F. and the pressure 45,000,000 pounds per square inch, or approximately 20,000 tons per square inch.

We know that through this central core certain waves are not transmitted and yet these waves are transmitted by solids. It is therefore most probable that the central materials of the earth, because of the temperature, are in a non-solid state. On the other hand, because of the enormous pressure the core is maintained in a state of plasticity and high viscosity.

In the earlier paragraphs we have mentioned the densities of the outer layers, varying from 2.7 to 4. What of the densities of these inner zones, and of the earth as a whole? The approximate densities of the outer zones could be measured directly as materials such as granite, basalt and olivine are readily available, but it is obvious that the deeper layers can only be subjected by us to mathematical treatment.

It has long been well known, and we have already said, that there is a definite and measurable attraction between bodies of matter. In the case of the earth and smaller objects we call this attraction 'the force of gravity', but the force is there in even quite small objects. Because of this it is actually possible in a small laboratory to weigh the earth itself! We must have a fine and sensitive pair of scales and a small and a large leaden ball. The small ball is placed on one of the scale-pans which are then very delicately balanced. The weight used to maintain this balance is, of course, an indication of the pull of the earth on the small ball. The larger ball is placed *under* the scale-pan and immediately below the small ball. The additional attraction of the larger ball, feeble force though it is, can be measured on the balance and there are thus available figures showing (*a*) the attraction of the earth alone on the small ball and (*b*) that for the combination of the earth and the larger leaden ball. The comparative pulls of the earth and the larger leaden ball can thus be assessed, and, since their sizes are known and the weight of the leaden ball is known, it is a simple calculation to get their respective densities and the weight of the earth itself. This is only one way of doing this apparently formid-

able task and there is at least one more accurate way of doing the experiment.

Such calculations, and those of allied methods, show that the average density of the earth is 5.5. As the outer layers average from 2.7 to 3 and 4, it is obvious that the innermost layers must be comparatively heavy to make this general average and investigation shows that the great inner zone, the so-called 'liquid' core, must have a density of just over 8. The evidence of the metallic meteorites, those stray fragments of our solar system's debris that occasionally fall on the earth, shows that they are composed of iron or nickel-iron which has a density very similar to that we require, and there is little doubt that in these meteorites we can handle and see a disrupted fragment, now, however, cool and solid, of the same material that constitutes the core of our earth.

Looking at this picture of the rotating earth, with its iron core and its stony outer crust, we are strongly reminded of the making of an iron ball in the foundry, for the central mass will be hottest and purest and the adulterations, the stony matter, will be on the circumference and will cool first and form a kind of skin, just exactly as appears to have been the case in the earth.

There still remain many arguable points. We started this chapter with a brief description of the various theories of the origin of the earth and mentioned the most satisfactory, the Tidal Theory, which suggests most closely this molten, cannon ball origin, for the Planetesimal Theory implies that the heat gradually arose in the centre as piece after piece of planetary material was added and that this heat gradually made its way to the surface. There may also be slight discrepancies in the calculations of the central heat, for, as we saw, they were based on figures derived from measurements in the outer stony crust where, in fact, the materials are poor conductors of heat and thus might cause us to over-estimate the inner temperatures.

The account we have been giving does indicate, none the less, the general facts of the formation and structure of the earth, the background of all life and our familiar surroundings, as they are generally accepted today. From now onwards we must leave the

considerations of the earth's structure for the examination and appreciation of its outermost layer, which is, in the first instance, properly the field of Geology.

CHAPTER III

THE EARTH—BACKGROUND TO LIFE

So far as the surface of the earth is concerned there are certain physical and chemical consequences of the mode of the earth's creation. We have assumed that, without much doubt, even the outer part of the globe was at one period in its history at a high temperature. We know also that at very high temperatures the solids and liquids that are familiar to us in everyday life would be more than molten, they would be vaporized and even gaseous. Once cooling started a very interesting series of events would take place, for chemical reactions would be possible and chemical compounds would be able to exist.

The upper temperature limit to chemical reaction may be taken to be something like 7000° F. so that when this stage was reached in the cooling process the first chemical compounds, almost certainly compounds between various metals and carbon, would be formed. At this stage some of the most vital substances we know would not be available but would be part of the immense atmosphere which must have surrounded the slowly cooling earth. This layer must have been much greater than it is now and probably extended for hundreds of miles upwards and exerted accordingly, pressures of tons downwards rather than the 15 pounds per square inch that we experience today.

When the temperature had declined to about 4500° F. further very important changes took place, for then oxygen would come into chemical combination with a host of materials and the very foundations of our world would be laid. The rocks that form our stony background are largely silicates, oxides and other compounds containing this vital element. These minerals would be formed, and formed to a very considerable extent, for we must regard the surface of the earth in these days as something of a bubbling cauldron in which materials deposited on the surface would sink

below to make way for fresh molten material. In this way the available oxygen in the atmosphere must have been used up at a far greater rate than now, though there would be at the same time enormous quantities in the air in combination with hydrogen as water vapour, and some would be obtained from the break up of carbon-oxygen compounds as the carbon was used in mineral formation.

When the temperature fell still further to about 3500° F., the convection currents of materials on the surface would largely cease, for the crust would be forming, a crust mainly composed of the silicate rocks. After this momentous event there would follow a long period of slow cooling and consolidation that may have lasted for millions of years. It is essential in the study of Geology that one should realize the immensities of time involved in its processes. In the history of our earth as known to geologists, a thousand years are indeed as a day in other histories. The study of the evolution of the lands, of the sea, and of the creatures that long after came to inhabit them, shows how deep Nature must have dipped into the vaults of time and yet how ample were the resources there.

When at last the temperature fell to about 700° F. the water vapour in the heavy atmosphere would be able to condense and heavy showers would fall to the surface of the earth only to be vaporized again. But at last conditions were such that precipitation could take place and rains of unparalleled intensity and duration fell upon the earth. The Flood had begun, and the waters spread over the warm and virgin rocks, forming the seas, filling the small depressions as lakes, bouncing from the glittering crags in the first waterfalls, to course over the slopes and swirl with others to form the primeval streams. The days of waiting were over and the agelong struggle against the rocks had begun.

We have said that the rocks composing the crust in these early days were largely silicates and over them the waters would spread unevenly for in the period of consolidation and early settlement there would be much inequality. The rate of cooling and contraction alone would produce ridges on the surface rather like those seen on the skin of a dried orange. Compared with the diameter of

the earth such ridges and folds would be of slight significance but to the observer on the surface they would have appeared as the first hills and mountains. It was upon them that the waters would first react. The process of erosion was started, the gradual but inexorable wearing away of the rocks by streams that cut their paths on the hillsides and the mountains. Water is a slow but good solvent of materials even as hard and smooth as glass, and each fragment of rock, each grain of sand, that was worn from the rocks was used as a chisel in the streams and rivers to help in further carving. If we study any modern river we note how determinedly it attacks its banks, straightening out bends, undermining wherever it can, and using stones and pebbles to form pot-holes and to scour and deepen its bed. This is especially the case where the river is comparatively young and where it rushes headlong to the plains or to the sea. In the case of older streams, where the slope of the bed is less and where progress is impeded by the amounts of material, fine silt and sand, that it has carried in its struggles, the rate of progress is naturally slower. These earliest streams would be fierce in their attack, scouring and carrying the maximum amount of eroded materials. As soon as they reached the primitive plains, the lakes or the sea, they would gradually drop their load of sediment which would become the basis of the first sedimentary rocks, rocks like the sandstones, limestones and clays that we know and use today.

The cycle of erosion that was started then has continued ever since. Nor is it merely a question of the rocks, for we can observe the results of the battle between what we call the elements and the works of man in all parts of the country; the erosive and corrosive powers of the atmosphere, of the waters of the rivers and the mighty force of the seas, coupled with the less spectacular but none the less powerful forces of the wind and the snows, and the alternating effects of heat and of frost. The geological process is one of relentless attempts to level the surface of the earth until these forces have no vantage point and until the slope of the lands is too gentle for the sluggish streams to have any incisive effect.

In the course of this never-ending task the materials wrested from the land are scattered far and wide. They are dropped more

or less gently in the lakes and in the seas, from which some again are cast upon the shore by the tides and the violence of the gales. Some of these materials become the sandy beach layers that may later be consolidated as sandstone. Some of the carried sediments are laid out in great and fan-shaped deltas but everywhere this matter is laid out to rest. If no interrupting process occurred the sands and the clays would gradually consolidate and harden, as, indeed, many of them do; but the geological processes are not only concerned with the erosion, transport and deposition of fine materials by wind and water. The young earth was yet unstable, the molten forces within were constantly looking for escape from their confinement, and the containing crust was not in complete adjustment. Actually, it still is adjusting itself in many places as we know when we read of earth tremors and great earthquakes. In those early days there must have been great disturbances of the crust both by earthquake and by volcanic action. The plains in course of levelling would be heaved up again, flows of lava and cones of material ejected from the volcanoes would be piled on ageing rock and newly made sediments alike, and on the newly formed hills and ridges, flows and volcanoes, the processes of erosion would start all over again.

So the cycle has gone on for many hundreds of millions of years. The primal rocks were attacked and their detritus was formed eventually into other kinds of rock which, because they were largely deposited as sediment by water and to a lesser extent carried by the wind, we call sedimentary rocks. Volcanic action, whether by the outpouring of lavas on top of them or by the injection of liquid material into them from below, has often burnt some of them up, and so baked and changed them, that they are called metamorphosed (or metamorphic) rocks because of their altered nature and condition. Sometimes the alteration was brought about not by the heat of volcanic products but by the heat and shearing and the grinding pressure of movement in the crust itself in its readjustments. Often, too, the weight of great sedimentary deposits laid later upon them has materially altered the early deposits.

Were the geological cycle a non-recurring thing then we could

expect to see preserved, and would no doubt be able to examine, the real succession of events in the rocks even if only in the later ones. It is unlikely that the stability of this geological existence would have stimulated anyone to pry into the deeper past. The fury and unceasing warfare of the elements on the living places of men, the knowledge of volcanic disasters on a great scale, and the experience of widespread earth movement and cataclysm have not only prompted men to inquire into the nature and history of these things, but the convulsions themselves, since they may bring the materials of the deeper layers to the surface and thrust the lower layers of the early rocks through and above their successors, and because they therefore make in places the order of sedimentation a topsy-turvied sequence, enable the modern observer to see, sooner or later, and in one place or another, the evidences of a tangled story which, in the course of the last two hundred years, have become largely reorientated and understood (fig. 3).

During long periods, incredibly long in some cases, these processes were constantly at work tearing down the fabric of the previous era and depositing the debris as a new series of deposits. Wind and weather played their parts and the settlement of the world saw at times great changes of climate, with polar-ice and snow where earlier (and often again in later times) quite warm conditions prevailed. In but few places have these processes left a series of layers that can be directly traced in historical sequence from their base to their summit. There are today some places (like the Grand Canyon) where a minute but important part of the world's history can thus be seen. Generally, however, the historical diagram can only be prepared by the careful study of sections exposed in countless river banks, canyons, cliffs, sea shores, quarries, railway cuttings, mines and bore-holes, and of the materials from the bare faces of mountains and from the very bosom of the sea.

To make the story anything like complete is clearly a task requiring many workmen, though the call of duty will take them to pleasant places and the resultant knowledge must interest all who read.

As a result of this great combined operation between professional

scientists and interested amateurs, a surprising amount of knowledge has been digested about the history of the earth and the forms that now inhabit it. The record is obviously not too easy to read. As in other stone tablets the writings are often obscure and fragmentary, many things are missing and the former content of these gaps can only be imagined. But looking at the story as a whole we can see these earliest rocks and the waters over them, we can see the changing and developing lands, strangely different from the world plan that we know today. The shapes of continents and seas alter from time to time. The seas, at first apparently empty, eventually show the spawn of life which grows and flourishes. In time this life attacks and overruns the lands hitherto so long barren and lonely.

The lands begin to show the sombre green of a new covering and, not long after, quite advanced forms of life invade this new element also, to spread and flourish, with constant change of pattern, until the picture comes to show the livelier hues of flowers and insects, and the forms of life more familiar to us today. In succeeding pages something of this pageant will be described in greater detail. We shall see the succession of the animals, trees and the flowers in their appropriate settings.

It is surprising what geologists can tell us. Some ancient rocks still bear the marks of the raindrops that fell upon them in their youth and we may learn the force and even the prevailing direction of the wind of those early days. A deposit may bear evidence of the climate, and the arid sands that tell of desert days will still show angled stones that forgotten winds have carved. Or the clays and muds may have been laid by the glacier streams and the boulders they contain will have the sharp inscriptions of their passage over distant rocks.

Impressions of leaves, the spores of plants, footprints and the bones of animals, abandoned lairs and the fragments of hasty meals take their places in the story. And we can even give, with a certain amount of accuracy, a date to the scene. In fact, before we come to the actual description of the varied scenes and players in this long history of the past, we must say something of this dating process.

In these days of the atomic bomb, based on the disintegration of

uranium, it may seem that the future of the world is uncertain and that the discovery of these powers has made no date in the future reliable. Paradoxically, it is through the emanations of this rare element that we are able with some precision to date events in the geological past.

It is generally known that in certain radioactive chemical elements, like uranium, there is a continual disintegration. This process starts with the atom of uranium which gives off helium, and the radiations plus heat. Actually most of the process can be followed, for there are given off 8 atoms of helium and the rate of their discharge is observable and recordable. When these 8 atoms have been discharged the uranium residue is lead. The process can be represented by a simple chemical equation, the figures in brackets after the elements being the respective atomic weights of the most common forms (isotopes) of the substances:

$$\text{U } (238.08) = \text{Pb } (206) + 8 \text{ He } (8 \times 4) + \text{heat } (.08)$$

U is the chemical sign for uranium, Pb that for lead, and He that for helium.

One of the interesting things about this process is that in natural conditions (as in contrast with the special and unique efforts made to disturb the uranium atom during the war) this process of disintegration was constant and was not affected by heat or pressure or any known physical or chemical condition. If, therefore, the rate of change from uranium to lead could be ascertained the amount of lead in any radioactive residue or mineral would by simple calculation give the age of the material. In actual fact other matters must also be taken into account in the calculation, such as the probable presence of the allied mineral thorium (Th: atomic weight 232.1) and for the fact that the quantity of uranium was constantly decreasing. At any rate, the general factor obtained from the whole series of experiments is the figure that 1 gram of uranium yields per year 1/7,600,000,000th gramme of lead, so that the age formula of a mineral, rock, etc., can be obtained as

$$\text{T} = \frac{\text{Pb}}{\text{U}} \times 7,600,000,000.$$

From a study of many uranium-bearing rocks and minerals the

age in years of many of the world's deposits has been obtained. Some of these figures are incorporated in the Calendar of Life. One of the oldest rocks whose age has so far been determined in this way is from Karelia in Western Russia (between the White Sea and Finland) and is about 1,850,000,000 years old.

The Karelian rocks belong to that geological period which we call the pre-Cambrian so that it precedes the geological periods that we shall have principally to consider in the following pages, but it is not itself anywhere near the beginning of the earth's history. From this early figure, and the many other figures that much research has since enabled us to calculate, it would appear that the earth as a geological structure is something like 3000 million years old. It is difficult for us to realize the true meaning of this immensity of time which is itself but a fragment of the age of the solar system. Geological studies are confined to the latter half of this period; the earlier half, in which the world was being developed and perhaps prepared for the spark of life, lies mysteriously and darkly far away in the mists of time. During these long ages no life was on land or sea, no green thing covered any part of the earth. The sounds were those of the wind and the rain, the roar of the sea, the flaming splutter of the volcano and the rending crash of the earthquake.

Towards the end of this period, about 1500 million years ago, the evolution of the simple fundamental unicellular form of life was beginning, but whatever it was, and however widespread it became in these early times, cannot be discerned by us because of the great distortion and pressures that inevitably have been exerted on the foundation rocks in which otherwise it might have been preserved.

About 600 million years ago, at the dawn of the geological period known as the Cambrian (since it is so typically developed in Wales), the rocks began to bear more clearly the evidence of life that we can understand. From those days to this the record and nature of the rocks are the fields of most geologists' investigations.

For those of us who study the development and evolution of life from this period onwards, the picture is one of increasing interest

and fascination as we see the gradual formation of higher and higher forms of life until at last the mammals appear, and, at the peak of their development so far, man himself emerges. Compared with the vastness of time on the earth, the mammalian record is short. The earliest of mammals were evolved about 150 million years ago and most of their development has been accomplished in the latter half of that time. Man is yet a newcomer, with a history at most of a million years, which is a mere scratch on the surface of earth's time.

Man, the animal, has none the less some qualities that his predecessors never attained. We do not know if he will survive so long as many past creations or what directions his future trends may take, but he has developed the faculties of reason and imagination, the power to alter and so to dominate much of his environment, and above all, to communicate his experiences to his fellows. His records are more generally useful and easier to read, even if they are infinitely more transitory than the long records of the rocks from which they are inevitably derived.

CHAPTER IV

THE HISTORY OF FOSSILS

THIS record of the rocks to which we have been referring, and which is briefly and diagrammatically set out in the Calendar of Life, is a modern conception, for it is only within the last two centuries that serious work has been done upon it and that its accumulating evidence has been subjected to searching, and sometimes acrimonious, criticism.

Yet, and especially in the later years, the science has withstood much examination and many attacks and has shown that these objects of this biological field conform to the laws of evolution so far as we can interpret them and that the science itself can add definite and confirmatory evidence to that provided by experiment and embryology.

This study of life is known as Palaeontology, a compound of Greek words that suggest the study of ancient life (Greek: *Palaios*, ancient; *ontos*, being; *logos*, science). The pieces of evidence with which the science principally deals are known as fossils, from the Latin verb *fodere* to dig, and rightly suggests that many of these things are dug out of the earth. There any many ways by which they are disclosed, such as the erosive action of water and of its waves, and the activities of man in quarries and other engineering works whence they are quite often accidentally discovered. This being so, many thousands of fossils must have been seen during the earlier days of the human historic period. Fossils have long been plentiful in the countries which border the Mediterranean, and the Greeks and the Romans were familiar with them. They must also have been observed by earlier peoples even if we have no records of the observations. Probably the earliest association between man and a fossil is the fossil shell that was among the amulets worn by a Neanderthal man whose skeleton was found in France. The fact that it was worn as an amulet would tend to show that he did not regard it as a common and everyday piece of material.

The Greeks and the Romans, on the other hand, have left records of their thoughts. Herodotus, who travelled in Egypt and Libya so long ago as 450 B.C., did not fail to observe fossil sea-shells in the desert and he rightly concluded that they had been left there after

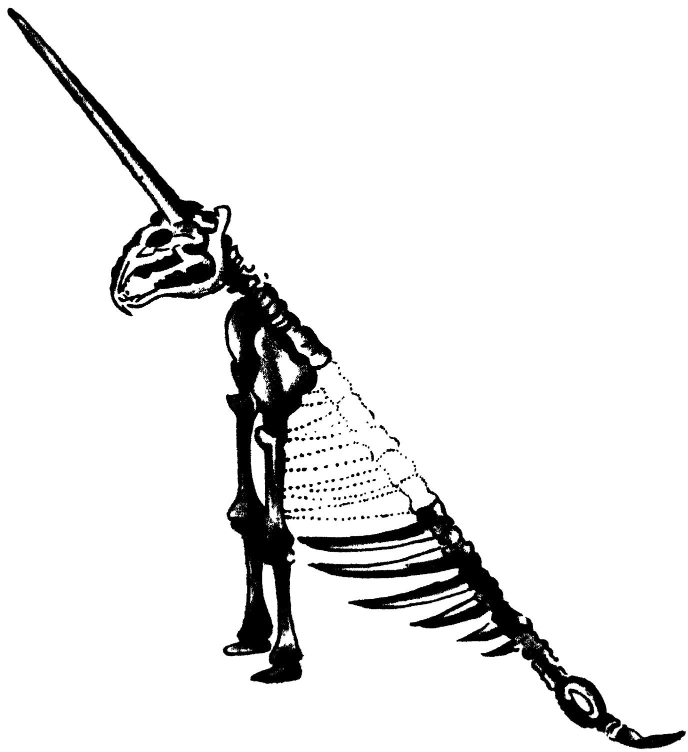


Fig. 4 A UNICORN
From a reconstruction by O. von Guericke, published 1749

the disappearance of the waters. At the same time there was a school of thought which believed that life could be generated spontaneously. Aristotle, the great philosopher and writer of the fourth century B.C., dealt extensively in his *Historia Animalium* with the characters of the spontaneously derived members of various animal groups as compared with the natural offspring, and he decided that there was always something a little inferior about the spontaneous types. He

obviously considered the fossils to be organic in origin but derived from the rock-materials by some plastic force which he could not explain.

His reputation was so considerable that this idea prevailed among his contemporaries who were content to regard these objects as natural curiosities. His pupil Theophrastus, however, considered that these organic remains had developed from seeds or eggs scattered in the rock materials and that they had developed and lived in the cavities of the rocks but had eventually become petrified. These two views have at least this in common, that the fossils were recognized to be organic remains.

Though sporadic observations appear in subsequent literature, little advance from this point was made until the revival of learning at the beginning of the sixteenth century.

This revival of learning, accompanied as it was in Italy with a great deal of excavation work, re-introduced the problems, for the digging of canals and other works produced large numbers of fossils which, on comparison, revealed their kinship with many of the forms then existing along the Mediterranean shores. Controversy was inevitable and fierce discussions ensued. By some, these organic remains were regarded as mere sports of nature, by others, as indubitable records of a past preserved in some peculiar way, while yet others frankly regarded the fossils as products of the ingenuity of the devil.

At this time there was living the great Leonardo da Vinci, who was not only a great painter but also a very competent engineer, and his pronouncement was strongly in favour of the true nature of these remains, namely that they had once lived where they were found. This did not settle the controversy which raged as an earlier parallel to that which Darwin was to start later with his theory of evolution. None the less, about a century later, Steno, a professor in the famous University of Padua, made so striking a collection of fossils that it was impossible for men of any intelligence to doubt that the fossils were other than the real relics of once living things. It is interesting to note that today much of Steno's collection is housed in the Sedgwick Museum of Cambridge University.

Fig. 5 A DINOSAUR FOOTPRINT (IGUANODON)
After Dollo, 1883

Although this idea became accepted, the difficulty still remained of explaining how the fossils came to be where they were and by what agency they had been preserved. By many the Flood of Biblical history was invoked as the full and final explanation. Men rushed from one extreme to the other. The despised sports of nature and the lures of the devil, the peculiar products of an inexplicable plastic force at work in the rocks, these same objects became the interesting relics of a sinful world destroyed in the Flood. Men who should have known better rushed into print, and a physician, who might have had a better knowledge of anatomy even in those days, published a work on certain skeletons that had been found in lake deposits at Oeningen in Baden, Germany. These he declared to be the remains of human beings drowned in the Flood. The text-figure (fig. 7) shows a famous example described by this Dr. Scheuchzer as 'Homo diluvii testis' which means 'man a witness to the deluge'. The skeleton is not in fact that of a human being at all but of a giant salamander (now called *Andrias scheuchzeri*) which is closely related to a species still living in Japan. Two vertebrae of a fossil reptile were also described in this book with the awful comment that they were 'relics of that accursed race that perished with the Flood'.

Fig. 6 ARCHAEOPTERYX
The skeleton of the earliest known bird

Of course, many other people in many other places made mistakes too, even if they are not so well documented, but one interesting and rather pathetic case may be mentioned. At the same time that Scheuchzer was writing his solemn treatise another learned man, not so very far away from him, at Würzburg in Germany, was compiling a volume on some extraordinary objects that he and his pupils had found. The man was a professor who delighted in taking his students on excursions to a favourite spot where ample fossils could be found. In an endeavour to provide their professor with an abundance of pleasure his students began to carve forms of animals and plants on stones which were placed where the professor would be most likely to find them on the next excursion. A very large collection of these 'fossils' was obtained and the credulous gentleman described and figured them in a book which is very rare today. The professor's name was Johannes Beringer and the book he wrote was named the *Lithographiae wirceburgensis*. It was, alas for him, published in 1726, the very year when Scheuchzer was describing his fossil sinners.

Beringer continued his researches with enthusiasm but he was at first puzzled and later horrified when he began to collect rocks with Hebrew inscriptions, and eventually his own name, upon them. He realized too late that he was the victim of a cruel joke and endeavoured to save his name by repurchasing all the copies of his book that he could get. In this he was so far successful that it is a rarity today although the British Museum has a good copy. But in the process of saving his reputation he spent all his money and eventually died a poor and broken-hearted man. His collections of so-called fossils are well known because his family, in a misguided effort to restore their fortunes, republished his work. His specimens are still preserved in the Naturalienkabinett, Bamberg, and some of them were shown at an exhibition in London in 1931.

This process of supplementing nature has been tried since Beringer's day, and doubtless will occur again, but probably never on so spectacular a scale. If it contributed nothing to the professor's fame or happiness it at least drew some attention to fossils and their nature.

We have mentioned above that fossils may be found in river banks, in canyons and in cuttings, on the sea-shore and in quarries, and on the surface of the ground itself. Since geological deposits are rather like the layers of a cake, with the oldest at the bottom and the newest at the top, it might be thought that even with great diligence only a fragment of the fossil remains of life had been studied. That this is not generally so is due to the fact also mentioned, that the stresses and strains in the earth's crust have caused great deposits to tilt and bend and even to become inverted (fig. 3). As a result enormous deposits are known throughout their *depth* because it appears on the surface *sideways*.

During the last two hundred years enormous advances in geological knowledge have been made. Thousands of exposures of many different kinds of rock have been examined all over the world, from pole to pole and from the oozes of the ocean's depths to the frozen slopes of Mount Everest. Not only are the successions of the different rocky layers known and their relative ages established, but large numbers of the forms of life that they contain have been minutely described and compared with living forms and with other fossils. In this way the calendar of life has been fairly well substantiated. For this fact many of the early and assiduous workers must be praised, and especially an English civil engineer with the homely name of William Smith. In the course of his profession, which compelled him to travel widely throughout the country and to study many excavations, Smith made an extensive collection of fossils, now in the British Museum, and made many charts, maps and written observations on the relative positions of the strata. One of his most important papers at this time was his *Stratigraphical System of Organized Fossils* published in 1817. Smith, because of his realization of the importance of the respective layers or strata has become known as the 'Father of English Geology'.

At the same time in France great advances were being made in the study of the nature of the fossils themselves and the foundations of what is called Comparative Anatomy were being laid. This work was being done by men whose names are now famous throughout

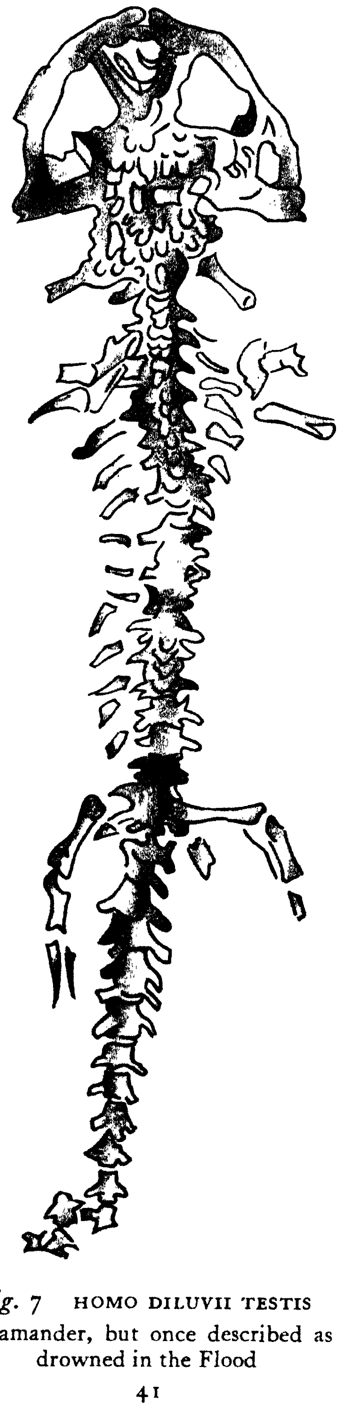


Fig. 7 HOMO DILUVII TESTIS

The skeleton of a large salamander, but once described as that of a human being drowned in the Flood

the world — Cuvier, Lamarck and, later, Sir Richard Owen and others in England.

This fact is mentioned not merely for historical reasons. It has been stressed that to many, fossils were regarded as sports of nature, as freaks and essentially peculiar things. Throughout the years men have oscillated in their opinions from the sublime to the ridiculous, from the commonplace to the fantastic. While some regarded the finding of large bones as truly the relics of an animal long dead, others inclined to a more imaginative explanation and legends of giants and strange creations grew. It is possible, though it is unlikely, that the dragon of mythology, once so important and widespread in folklore, may have owed something to fossils. Too hasty interpretations and over imagination which invested some of these early finds with a quite fantastic character had the result that impossible reconstructions were made (see fig. 4). Instead of trying to relate the relics of the past to some of the present-day forms, these early romantics apparently tried to construct something as inaccurate and impossible anatomically as they could.

The serious and comparative researches of the French scientists Cuvier and Lamarck, combined with the work of Smith in England, laid the foundations of serious palaeontology, whose results were constructive. The bones of so-called giants, for example, were more soberly and more instructively discovered to be those of fossil elephants. These men did more, too, than lay the foundations of palaeontology, they taught much about the ways in which fossils are preserved.

It is obvious that a dead animal does not necessarily become preserved for all time or get buried where it falls. We know only too well that the forces of decay soon remove the carcass. How seldom do we see the remains of a sparrow! Yet from the past we have some fossils preserved in almost perfect detail.

The process of preservation is a chance that gently overlying sediments or percolating waters may cover and consolidate the remains without disruption. Throughout the long years afterwards, the consolidated bed must be spared the processes of erosion, compression and distortion if we are subsequently to find a well-

preserved and useful fossil, and this again is a matter of very great chance. Granted that our fossil has escaped the numerous destructive forces, what are the odds against its appearance in stream or quarry or other exposure? Even there is it likely to be seen, especially by someone who appreciates its importance? The whole process of fossilization, the collection of fossils and indeed, following on these, the study of fossils has depended much on fortune. From the thousands of particles of evidence a fascinating body of facts has been obtained by what is no less than a fine piece of detective work. We can now follow the tangled story almost from life's inception, far away, to the coming of man, geologically so recent.

We can, in imagination, pass through the ages, clothed in their colours of varying hues, and inhabited by many different kinds of life. Some of those forms have passed the torch of survival down the years. Other forms have had their day, have died, without hope or progeny, and would be forgotten but for palaeontology. But the time has come when we must leave the historical conception of the whole for the close study of its constituent parts. We must seek the germ of life and see its growth flourishing through the ages until it reaches what we must think is its climax in the world that is around us today.

CHAPTER V

THE ORIGIN OF LIFE

PERHAPS one of the most primitive instincts of man, only a little less urgent than hunger and self-preservation, was concerned with death. Most animals are, and certainly early man would be, conscious of the great change that takes place suddenly in one of their fellows. Uneasiness, fear and wonder are aroused and this primitive fear and bewilderment are the basis of many mythologies. To primitive people and to many millions of people living today, to question the difference between life and death and living and lifeless things (which is not the same question) would seem absurd. But is it so very absurd? Every day our bodies absorb material that is certainly lifeless but our chemical processes convert it into the very stuff of life. It is true this process is accomplished or started by a living agent. Are we so sure that in all the earth no similar agent exists, though unregarded by us as living and that some tiny 'chemical factory' is not converting lifeless material into life; that, in fact, the line between lifeless and living cannot surely be drawn?

'Of course,' people will say, 'all this is nonsense. We know that animals and man and trees are living and that they die eventually, but rocks and metals and things like that never go through the motions of life.'

If one can tell at a glance the difference between living things and those that do not possess that faculty, it should be comparatively easy to set down on paper the criteria of what we call life. Let us therefore examine the definition of life as it is generally given.

The physiologists have postulated these six essential processes of life:

1. Renewal and repair of substance.

2. Absorption of energy and the performance of work.

3. Power of response to changes in the environment (including irritability).

4. Self-defence from other organisms.

5. Growth and reproduction.
6. Memory and intelligence.

Of this list it is quite obvious that neither the self-defence from other organisms, nor the memory and intelligence, could have been qualities of the primitive form of life. This leaves us with four other qualities all of which are commonly seen in the study of minerals and are readily demonstrable in the growth of crystals from solution. Even one that we have excluded can be applied to crystals, for the late Professor Judd wrote: 'The memory of crystals is far more retentive than that of any organism.' Mineral solutions may even show some form of self-defence against other 'hostile' solutions.

So the definition is not so easy after all and the reason why this is so is entirely due to the increase in our knowledge in the last three hundred years.

Before the seventeenth century sharp divisions in the classification of objects were easily noticeable, but the transitional stages were out of view. Soon, however, the invention of the microscope by a Dutch draper was to alter all this. During the years since that invention, more and more has been discovered about the structure both of living things and of matter, and one of the fundamental discoveries is that living matter of whatever nature is composed of cells. These little living units, apparently simple in structure but amazingly complex in nature, are the fundamental bricks of every living edifice, whether, as in the human body, of nerve or muscle, of brain or blood-corpuscle, of heart or skin.

The fact that the very essence of life was contained in these little building materials inevitably altered views on the very nature of life and of its origin. The nature of living things was now neither so obvious nor so clearly capable of differentiation. Further, the improvement and refinement of the microscope only showed that there were important living things of a slightly different kind that eluded even its new and intensive powers.

In recent times it has been possible to examine the new unit of life very extensively; to assess its physico-chemical quality, to probe the nature of its constituents, and to experiment with 'the little area' (the nucleus) that governs its growth and reproduction. We

learn of the basic necessity of water for this unit; we see the limiting importance of the environment whether it be sea or land or air, or other cells. We see ordered growth, and we see the break away from control that results in riot of growth, with resultant pain and distress to the integral body.

Views on the nature of the living tissue have long been altered by the cellular concept, but obviously a search for the primal form of life has been put back and reduced, if reduction it be, to the chemical, physical and other environmental conditions in which this cell could be generated in a world which hitherto had not possessed what we consider as any form of life.

It has been suggested by such famous scientists as Helmholtz, Lord Kelvin and others, that the germ of life was borne from another planet, either on a piece of planetary material or even by 'light pressure'. The latter process may be explained by stating that the action of light rays on a small body presses it backwards and a common demonstration of this power used to be seen in jewellers' windows where sometimes there was exposed a little shaft with four vanes in a vacuum. One side of the vanes was light-coloured, the other side was coated black and the rays of sunshine falling upon the black surfaces caused the vanes to rotate. However, neither of these theories would explain the origin of life, they merely transfer the problem.

Now if we examine the materials of life we discover that there are certain essential chemical requirements. They are water, carbon, hydrogen and oxygen, to the greatest degree, and quite a number of other substances such as calcium, sodium, nitrogen, phosphorus, and sulphur, to a lesser extent, all of them incidentally materials more or less soluble in water at various temperatures.

We have seen in earlier pages that at one of the stages in its cooling process, the earth had a heavy moisture-laden atmosphere and highly chemical shores. At such a time there would be conditions of temperature and an abundance of materials from which such a compound might be derived, did we but know the way, though we have not so far been able to reproduce them in a laboratory. But we do know some confirmatory details. We find

that in physico-chemical reactions there are some especially favourable phases as, for example, where the liquid, the solid and the gaseous meet. These were all in such juxtaposition in this early formative period. In studying the so-called higher forms of life, including man, it is easy to examine the nature of the vital essence, the blood, which carries oxygen and nutritive materials as imports and which exports waste products from the tissues. The constitution of the essential fluid of this is a long-borne memory of the time of its first creation. It has the constitution of the early sea water, then, of course, less salt than now since the salty products of the earth had not been so much deposited in it.

Research shows that the fundamental constituents of protoplasm — the stuff of the cells — are proteins. These, in turn, are highly complicated forms of what are called amino-acids which can be manufactured in the modern chemical laboratory.

In the last chapter we saw that in the early days of the earth's history there was an abundance of carbon dioxide in the atmosphere and in solution in the waters. As a result of electrical disturbances in the atmosphere and associated with the rainfall, there would almost certainly be nitrogen products also in the water. Therefore, given a satisfactory amount of sunshine, and especially of its ultra-violet rays, the way was clear for the manufacture of carbon-nitrogenous compounds, an important step in the production of amino-acids.

We are led in this and other ways to consider that these heavily chemically charged surroundings with an abundant gaseous atmosphere, and with the sea, the water that has been so well named 'the menstruum of life', so readily at hand, and the whole at a suitable temperature, might foster the chemical experiment but would not harm the result. We cannot conceive this as any deliberate affair but rather as an event where all the ingredients were at hand at the time when some activating agent was also there. The nature of the activating agent is the rub. We know, however, of many agents which have the curious effect of producing chemical reactions without themselves being involved. We call them catalysts and they are the first agitators.

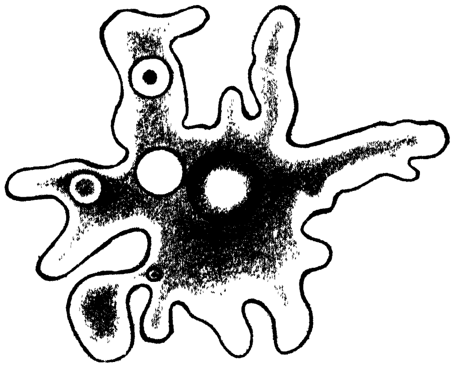


Fig. 8 AMOEBA PROTEUS
Actual size about one hundredth of an inch

In this instance we can only assume that such an agitator was present. It incited, at a peculiarly appropriate time, the chemical mob which reacted. The reaction, we may presume, was not a riot but a little froth of jelly-like material. This little jelly would in time form a 'skin' around itself to keep some check, but not a complete check, on the water outside. The varying pressures and physical forces would cause it here and there to bud and to move, even perhaps to divide. The chemical solutions ultimately to become necessary for food would be absorbed and the unneeded deadweight, the waste products, would be abandoned in response to some primitive law of buoyancy. This unknown and imagined object, so like some of the growths developed in certain mineral solutions, has been given the name *Protobion* (from the Greek: *protos*, first; *bios*, life).

If we examine one of the simplest and readily available forms of life that we can obtain today, the *Amoeba* (fig. 9), we see a little creature that in its outlines resembles this first form of life, but it is only a resemblance. For *Amoeba* is no simple creature; it is a highly organized little body which bears within its small compass many of the faculties so highly and more specializedly developed in our

bodies. We can observe the *Amoeba* under a microscope or even nowadays on a film. We see it push out little bud-like processes and so move along. It surrounds and ingests particles, absorbing those that are useful to it and ejecting those that are not. Its material is a substance that is neither a fluid nor a solid, but what we call a colloid, a gluey mass, rich in granular matter that can be seen to move in streams. In one part of the mass of material may be seen a small disc — the nucleus. This is the heart and brain of the creature. It governs the little protein-making factory that the cell is. It gives the word when the cell will divide into two, itself dividing into two as a preliminary so that the newly derived factory will not lack an overseer. This nucleus is rich in a material which we call nuclein, and without this no sub-division, that is no birth of a new cell can take place. One of the most important constituents of this substance appears to be phosphorus, available too in the primeval times when we think *Protobion* may have been developed.

The amazing complexity of our modern *Amoeba* is merely an index of the enormous length of time and of the chemical and physical development that life has needed to produce the perfect cell. Given the perfect cell, all sorts of blocks of units could be built and were built, as experiments on the ever increasing, ever spreading and all conquering life. What many of these forms were like in the sea, on the land and even in the air we shall see in the pages that follow.

CHAPTER VI

THE EARLIEST ANIMALS

WE have ended our survey of the probable origin of living matter with a reference to that so-called simple and staple feature of the zoological laboratory, *Amoeba*. But we find on examination that this minute animal is by no means simple, indeed, it is complex and must be far removed in time and development from the peculiar chemical compound that we have called *Protobion* (fig. 9).

Our ideas of the development of the early forms of life are conjectural and very far from simple. We can, however, probably construct a mental picture of the original forms from the study of the simplest types of life that the microscope reveals to us today. It must also be remembered that there are some forms of life which are so small that they almost elude the ordinary microscope and cannot be captured even by the finest porcelain filter used in the bacteriological laboratory. For this latter reason they are known as 'filter-passers', and although they can very seldom be seen, their presence is detectable by the reactions that occur from tests on, or from the injection into animals of, the filtrates that contain them. Such reactions are well known since many of these filter passers, or viruses, are the cause of human diseases such as the common cold, influenza, measles, mumps, infantile paralysis, yellow fever, small-pox, and cow-pox (vaccinia).

Thus, though their presence and effects are demonstrable, we cannot know much of the structure of the little organisms themselves. It may be simple or complex, but the whole cycle of its life takes place in a 'body' less than one five-thousandth of a millimetre in diameter, since this is the limit in size that can be seen under the ordinary microscope in yellow light; and most of the filter passers elude the microscope. The development of the electron microscope has brought about a new phase in the study of these micro-organisms and photographs have been published of some of the filter

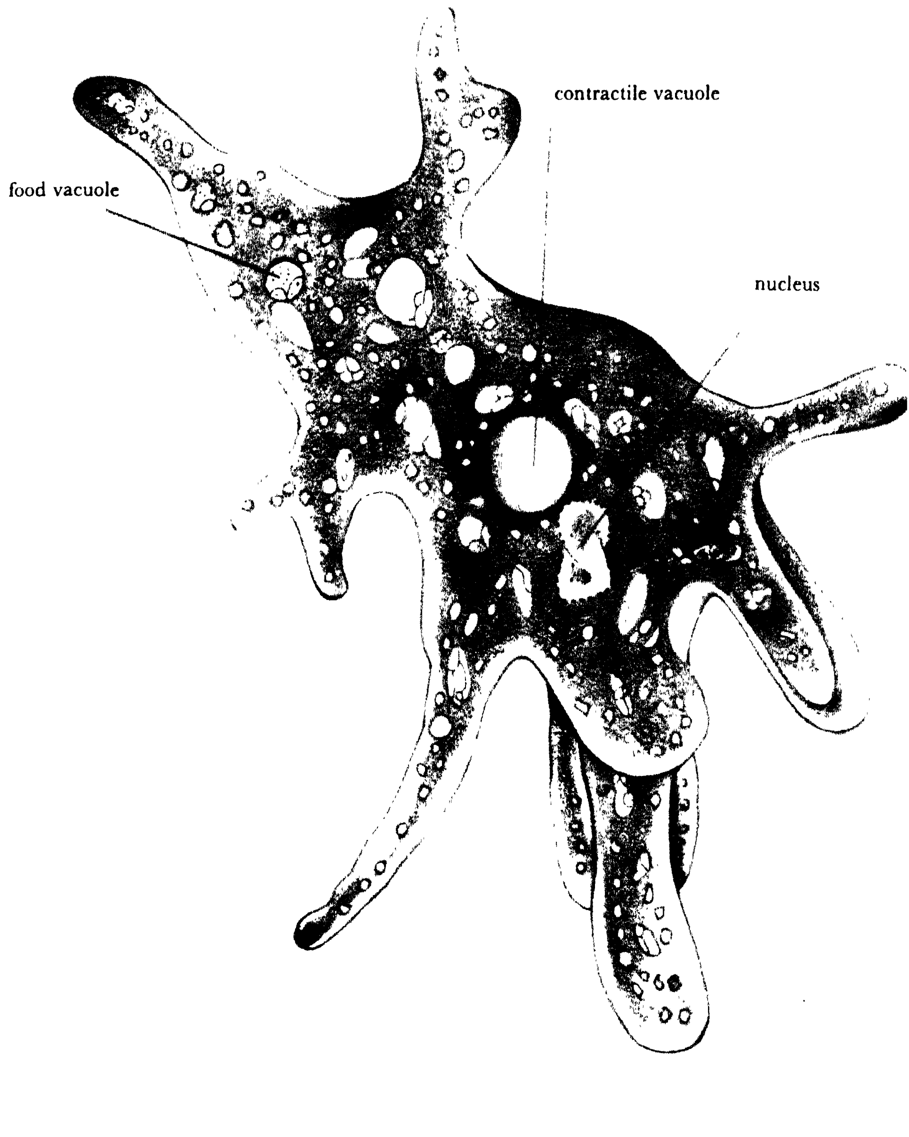


Fig. 9 AMOEBA LESCHERA
Very much enlarged

passers of less than one ten-thousandth of a millimetre in diameter.

The recently discovered virus causing infantile paralysis is said to measure 1/40,000th of a millimetre in diameter.

The infinitesimal size of these important organisms puts a new complexion on the ideas we have of life's inception. However important the event was as a chemical experiment it was certainly no spectacle that could have been observed by a human eye.

The few filter passers that are just within the limits of microscopicalvisibility have been proved to be bacterial in nature, so that we may pause for a moment to consider the bacteria, and the mere definition of them raises problems. They are defined as 'non-chlorophyll vegetable micro-organisms' and most of these terms are new to us in these pages at least. What does chlorophyll mean and why bring in the vegetable?

When we study the present-day unicellular organisms we find that we can divide them roughly into three main groups, some of which are regarded as being animal, some as plant (vegetable), and some as intermediate since they possess certain of the qualities of both. But all are protoplasmic and nearly all have a demonstrable nucleus that governs the growth and multiplication of the cell.

The fundamental differences between the unicellular animals and plants, like those between their higher relations, are (1) the method of feeding and (2) the nature of the layer surrounding the protoplasmic units, i.e. the cell wall. The animal uses for its food substances that are already elaborated, either animal or plant matter, but the plant makes the food it needs out of the air, the soil and the waters. Even the most primitive forms of plant life are little chemical factories extracting carbon dioxide from their surrounding elements and giving off oxygen. All animals, on the other hand, take up oxygen and use it for fuel, principally to break down the food materials they have ingested, and they give off carbon dioxide. This interdependence between the two is of great interest. Animals are fundamentally dependent upon plant life. Even if we are not vegetarians ourselves we eat the flesh of animals that were. Under these circumstances there arises the question, rather like the old one of the hen and the egg, as to which form was

developed first. From the simplicity of their feeding arrangement (however elaborate that 'simplicity' may be) it would seem that the unicellular plant-organism more nearly conforms to the *Protobion* specification, although some distinguished zoologists do not agree on this.

The plant cell does, however, make a logical point on which to focus our attention and nearly all that it contains is quite similar to that in the animal cell.

All the material in the cell consists of protoplasm, which is a colloid (that is, it consists of a watery fluid in which granular matter is *suspended*, not dissolved). Protoplasm is an extremely familiar substance whose essential nature we do not really know. We can take it into the laboratory but we cannot analyse it, for so soon as we start to do this it is dead and no longer protoplasm, for dead protoplasm is not at all the same thing. Dead protoplasm consists of carbon, oxygen, nitrogen, hydrogen, sulphur and the sulphates and phosphates of potassium, calcium and magnesium (the amounts of these substances are approximately in that order), but how dull is this catalogue compared to the surging stream of life!

In the plant cell the protoplasm is contained by a wall of cellulose, a substance that is chemically akin to starch, whereas animal cells are said to be naked, but all living substances contain this protoplasm, which Thomas Huxley called 'the physical basis of life'.

Under the microscope we can see its streaming movements, moreover we can notice two other things. Firstly, that if we stain the cell with a dye, one portion of it will stain a little darker than the rest. This is the nucleus, the heart, brain and controller-general of the whole life of the cell. Without it the cell will shrivel and die; with it the cell grows and multiplies, and when reproduction takes place, when the cell material divides into two, the nucleus divides first and a new nucleus goes away with each of the daughter cells.

Secondly, the plant cell in its natural state contains green granules of a substance called 'chlorophyll', a name compiled

from the Greek words for 'green-leaf'. This chlorophyll enables the plant, whether single cell or flower or tree, to trap and use the energy of the sun contained in the red and orange rays of the sunshine, to build up the inorganic materials, derived from the air, the soil and water, into the elaborate organic matter that is the basis of its food and ultimately of its body.

Thus feeding in plants is a building-up process, whereas in the animal the food, essentially organic, has first to be broken down and the materials then rebuilt in a different way.

The most primitive plants are, of course, aquatic and are called algae, from the Latin word for 'seaweed'. The naturalist can obtain them from any pond and can watch their life under a microscope. They are a fascinating group with many forms, some quite complex, but they all have chlorophyll to make use of the sunlight. Some of them even have little siliceous shells fitted in two halves, and these, because of this apparent cutting across of the shell, are known as diatoms (fig. 10). Their shells are found in the oozes of the sea where they accumulate in immense numbers. Actually, great deposits of rock derived from these oozes are known to geologists and one cubic foot of such rock contains more diatom shells than a man could isolate and count even if he were foolish enough to devote his whole life to it. So these deposits bear witness to the prodigality of nature and the immensity of time.

The plants we have been talking about so far have all been one-celled, but sometimes whole colonies of cells are gathered together presenting the appearance of a larger and complex form. As an example the common pond dweller, *Volvox*, may be taken. It is so common that often the pond waters are coloured green by its presence. On close examination it will be found that it is a hollow sphere of cells which can be seen, under the microscope, to be continually turning. It is able to do this turning movement through the presence of two minute, whip-like threads of protoplasm, known as flagella, which project from the outer wall of most cells and act as oars to keep the *Volvox* rotating.

Continued microscopical examination shows other interesting things too. Division of the cells goes on in this alga by fission, that

is, by simple splitting into two, the cells affected being those without flagella. But the process of division goes on much further, for the new cells divide again and again until a tiny new colony is formed. Several of these 'daughter' colonies can often be observed within the parent sphere and they remain there until they are liberated by the breaking up of the *Volvox.*

But this alga does not multiply by fission alone for there is another, a sexual, form of reproduction. It appears that certain of the cells without flagella are male and others are female and the congregation of a male and a female cell produces the beginning of a new *Volvox.* Here, then, we see a similarity with a much higher order of things an apparently simple form of life but with certain of its cells devoted to special purposes as locomotion, reproduction, and so on.

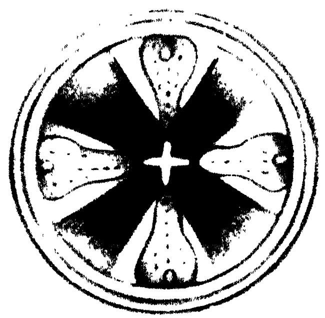


Fig. 10 SECTION OF A DIATOM
Greatly enlarged

From this example we may return again to the parallel stages of the Bacteria. These we have already defined as 'non-chlorophyll vegetable' organisms; that is, they are said to be plants, but they do not have the chlorophyll so characteristic of all other plants except the fungi. Examination shows that they usually have no demonstrable nucleus either. Chemically, of course, they are akin to the other forms we have discussed and 80 per cent of their bulk is water. Since they are without chlorophyll they are animal-like in that they depend on outside sources for their food, and since they are enclosed in an envelope often of a starch-like (polysaccharoid) nature, their food must be in a form that can be absorbed through the envelope. They divide and multiply with very great rapidity and a single bacterium can produce 17,000,000 new organisms within twenty-four hours (figs. 11 and 12). Fortunately, for both patients and doctors, there are several factors which can affect this growth rate.

Some of them divide by transverse fission, some longitudinally, and some in both directions. Some bacteria, the so-called higher bacteria, grow into long threads or filaments and these appear to be divided off into separate cells, so that again we have a complex of simple cells. Some of these cells at the ends of the filaments are set apart as sexual. They are set free from the parent bacterium and from them a new colony of the bacterium may arise.

It is difficult to place the bacteria as plants and it would appear that, generally speaking, they require organic matter as well as mineral salts in a soluble form for their nourishment. Some flourish only in an atmosphere of free oxygen, most require an atmosphere with a little oxygen, and others need no oxygen (the so-called Anaerobes such as *Clostridium tetani*, fig. 11).

Thus, in the absence of chlorophyll, and in their manner of feeding, and in the nature of the food supply, the bacteria would appear to show no characters that would qualify them to be regarded as plants.

At the most we can say that they are in an indeterminate position, in which respect they resemble a few small organisms that we may deal with now, the Flagellata (fig. 13).

The first form of this group that we mention is a tiny inhabitant of the ponds and ditch waters called *Euglena*. It has a narrow boat-shaped body, rounded at one end and pointed at the other, but unlike most boats the rounded end is the front, and this front has two features worthy of notice. One is that there is a minute opening in the cuticle or 'skin'. This is very narrow and short, but it perforates the cuticle and leads to the inner protoplasmic substance. It has often closely placed to its inner end bubble-like contractile vacuoles and these appear to discharge their materials into it. The little opening is also said to take in solid food materials and it is therefore often called a pharynx, after the upper portion of the gullet in higher forms of life.

The opening is often also called the vestibule and within it arises another interesting feature, a long thin whip-lash, the flagellum, whose lashing motions tow the *Euglena* through the dirty waters in which it normally lives.

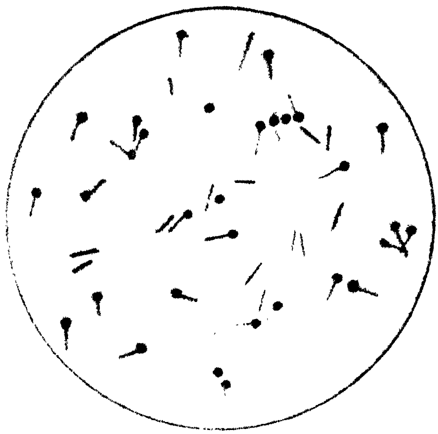


Fig. 11 CLOSTRIDIUM TETANI
The bacillus of tetanus (lock-jaw). Size about one five-hundredth of an inch

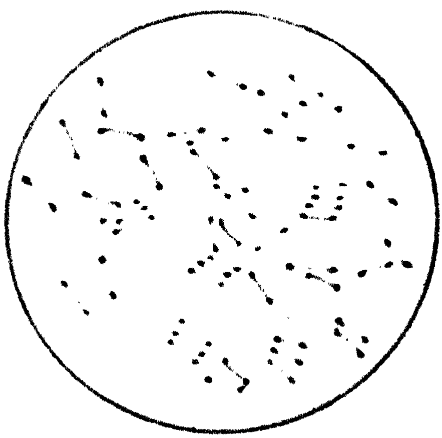


Fig. 12 CORYNEBACTERIUM DIPHTHERIAE
The bacillus of diphtheria. Size about one eight hundred and fiftieth of an inch.

Near the pharynx is a little reddish spot, the pigment or eye spot, which is supposed to be sensitive to light.

In addition to these features there are two other remarkable characteristics associated with *Euglena*. One is the series of body movements that the organism contrives in addition to the towing movement of the flagellum. These are so characteristic — a swelling, twisting, turning motion — that this kind of movement is called euglenoid. It has really to be seen to be understood. The other, perhaps more obvious character, is the green colour of the animal which in fact contributes with that of the accompanying algae to the green colour of the ponds and ditches where they live. Microscopic examination shows that this colour is due to granules containing chlorophyll. There is some controversy nowadays as to whether this form is not a protozoan (animal) carrying minute algal (plant) passengers or parasites, but most of the earlier authorities were content to regard *Euglena* as a 'betwixt and between' form of life.

The presence of chlorophyll and the consequent form of feeding (for the escape of oxygen from it in water had been noted) marked it as a plant. On the other hand, the elastic cuticle (not cellulose) and the method of taking in material by the pharynx, marked it as an animal. There is an additional complication, for *Euglena* reproduces in the normal way by dividing longitudinally, but, like most of the Protozoa, under certain conditions it rounds off into a cysted form, and divides into a number of little cells within the cyst wall which later bursts, liberating them as young *Euglena*s. Now, while the normal *Euglena* wall is not cellulose, it does appear that the cyst wall of the reproduction stage is of cellulose like a plant.

These flagellum-bearing unicellular 'animals' are grouped together as a division of the Protozoa known as the Flagellata. Not all the Flagellata have a pharynx or chlorophyll, but the feeding habits of these forms are so similar to those of certain 'plants' that also lose their chlorophyll that the animal or plant argument is not affected. Some are the cause of disease, and that shown in fig. 13 is the parasite of African sleeping sickness, from the blood of a patient.

The last group of the Protozoa that we need deal with here are somewhat similar creatures called the Ciliata or Infusoria. They receive the first of these names because their locomotion is effected not through a single whip-like flagellum, but by means of a series of much shorter hairs, or cilia, so that these 'ships', in contrast to the bow-oared *Euglena*, are like the Roman galleys. There are other differences as well, particularly the presence of two nuclei, but they will be briefly mentioned in describing the two best known examples *Paramecium* and *Vorticella*.

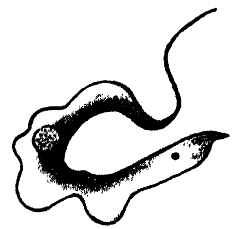


Fig. 13

TRYPANOSOMA GAMBIENSE

The protozoan parasite of African sleeping sickness. Size about one eightieth to one one hundred and eightieth of an inch

In biological and bacteriological laboratories, when certain solutions are left uncovered it is well known that they become contaminated or invaded by spores of very small fungi (moulds), algae, and these protozoa. The most famous example of this invasion in our time was the spore of a mould, *Penicillium notatum*, that went on a culture-plate that Dr. Alexander Fleming was studying in September 1928. The fruits of that 'invasion', and the brilliant work of Sir Alexander Fleming and Sir Howard Florey, have made medical history, and penicillin has become a new household word. This invasion process is not haphazard, for the spores that are scattered and carried in the wind are not thereby necessarily dried up and dead. But they appear in a regular succession. First, the so-called plant spores and bacteria, then the Flagellata, and then, presumably because they feed on the Flagellates, come the Ciliata, very often represented by *Paramecium*, called from its shape, the slipper animalcule.

This minute animal is seen by the naked eye as a moving white speck, and since it is most often found in dirty water and as a scum on decaying matter, there would not appear to be much beauty about it. Under the microscope, however, it presents a more attractive picture.

It shares several characteristics with the *Euglena* we have just described (see fig. 14). It is somewhat boat-shaped with again the round end as the bow. Again it is contained by a thickened cuticle which in this case keeps its shape constant. Also, on its upper surface, there is a somewhat spiral pharynx or vestibule.

Over all of the surface of *Paramecium* is a pattern of oar-like cilia and these also line the pharynx. Their movement, a stroke and sometimes feather movement, propels, halts and turns the organism, while the swirling movement of those in the pharynx causes food particles or solutions to be taken in.

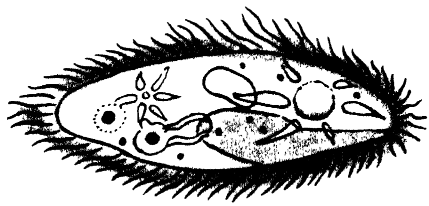


Fig. 14 PARAMECIUM CAUDATUM
The slipper animalcule. Size one sixtieth of an inch

There are two contractile vacuoles, one fore and one aft, and they seem under the microscope to alternate in action. As one contracts its fluid is seen to be injected into a number of small radiating channels around it on its way to the exterior.

Embedded beneath the outer 'skin' in many parts of the animal are peculiar rod-shaped bodies that can apparently be irritated. When this occurs they shoot out long thin hairs that act not only as organs of defence but as anchors. The rod-like bodies are consequently called trichocysts (i.e. hair cysts).

Paramecium has two nuclei, one large, the meganucleus, and one small, the micronucleus. They are close to each other near the inner end of the pharynx. The larger one controls the functions of the body and the smaller one is exclusively concerned with reproduction. Reproduction is again by division and by spore formation.

Vorticella is a more complex, flower-shaped, form with the cilia confined to the rim of the 'flower'. The 'flower' is further attached to a stalk which anchors the animal to some weed root or stem.

There are, of course, great numbers of algae, fungi, bacteria and protozoa. What has been given here is an elementary account of some

of the simplest and common animal forms that the naturalist and the student of biology can and will see in his studies. How far do they help the hen and the egg problem of life's simple original form? How fast do they establish the boundary between animal and plant?

We have said that the principal differences between the simple plant and animal are (i) the nature of the cell wall, which is cellulose and thickish in plants, and thin and cytoplasmic in animals, although *Amoeba* seems to have no covering at all. This distinction in most cases would appear to stand: (ii) The nature of the feeding process which is accomplished in plants by the building up of inorganic material into complex organic compounds by the use of chlorophyll and sunshine; and which in the animal is done by taking in and breaking down organic (often plant) substances and reconverting them to other organic compounds.

Yet we have seen that several so-called plants, the fungi and the bacteria, have no chlorophyll and that some of the latter are adaptable to an atmosphere devoid of oxygen. It may, however, be pointed out that the non-chlorophyll fungi (with the moulds) and bacteria are *adapted* either to feed as parasites on the elaborated materials of other plants or animals or on the decomposing products of the dead. They are thus not the simplest primitive type, the originators of the tree of life.

We have mentioned the flagellates, the simple types that are propelled or pulled by oar-like filaments. It is interesting that in some part of the life history of many unicellular animals and plants there is a flagellate stage and that this is still seen in the reproductive cells (spermatozoa) of most higher forms of life even including man.

Flagella occur in many bacteria, though some of them are now discounted and alleged to be merely the trailing portions of the bacterial cell-wall substance. So the primitiveness of a flagellum is open to some doubt also.

The animals we have been describing are, in fact, far from simple and we cannot see any minute and primitive hypothetical *Amoeba* that links a *Protobion* with the *Amoeba* we know, for it is complex in being able to live without chlorophyll.

We have come back to the chlorophyll, for in the primeval world the first formed living thing would, for a time, live alone, though Sir Ray Lankaster has suggested that albuminoids, complex chemical products, probably occurred. If it lived with the ability to use the sunlight, the air and the watery solutions, without a chlorophyll substance, *and in the absence of organic compounds*, it was different from any form of life we know now. We can only speculate upon it and realize that these unicellular forms we have described from the fauna and flora of today are in some ways close to the primitive stock. They are the modern representatives of the diverse and innumerable forms of living things that by constant reaction and elaboration formed long ago the foundation of all higher animals and plants.

Without some knowledge of the simple we could hardly proceed to the description of the complex, but as to origins 'the debate continues'.

The animals and plants we have been describing, and which are known to biologists today as the Protista, may be taken as some kind of example of the so-called simple forms of life of the early history of the world. We can be no more precise than that and we have no satisfactory record of, and but few clues to, the stages of growth and development from some of these simple forms as they laid the broad foundations of the flora and fauna of the earth during geological history.

The great developmental period of these forms, the pre-Cambrian, or Archaean, epoch as we all it (see Calendar of Life), occupied over one thousand million years, longer than has passed since the curtain was pulled aside to reveal the rich and varied fossils of the Cambrian. That immensity of historical darkness, of illegible record, will almost certainly never be satisfactorily probed or fully understood. We can attempt, as we have done, to picture the first unicellular form of life. From the study of the fossil record of the Cambrian epoch we have a good knowledge of the great number of highly developed and anatomically and physiologically complex forms of life that by then were well established.

Concerning that intervening time we can only guess. But if its

darkness is impenetrable, at least we can understand why this should be so. There are two main reasons, the nature of the then living things themselves, and the geological accidents and processes that would foster or prevent preservation or fossilization.

We imagine that practically all these early animals were soft bodied and we notice that most of them had no shells of lime or any other substance, or skeleton of bone within, or some other horny lining, or bony covering outside. It is therefore clear that there was nothing in their substance that was capable of being preserved, except under especially favourable conditions.

If one is familiar with fossils one realizes that what we call a fossil is, in most cases, only the shell or the hard skeleton of the dead animal. Only in exceptional cases, when the body was practically undisturbed and deposited in gently sedimenting water, in fine mud, for example, do we sometimes have an impression of what we call the 'soft parts' of the animal. We presume that most of the forms of life that were flourishing in the pre-Cambrian period had no such shelly or bony support or covering and all were aquatic. When they died their bodies would soon disintegrate. Yet in the course of that long time surely many, by the sheer incidence of chance, must have at some time been deposited in conditions favourable to preservation, or have developed some kind of shell or test. What has happened to them?

Let us imagine a soft-bodied animal, a marine worm or a jelly-fish (fig. 15) that has died in pre-Cambrian time. It has, we will assume, died a natural death and has slowly sunk, undisturbed and unmutilated, upon the fine silt or mud that happened to be below it. It has come to rest upon this, and in the succeeding days a gentle current has deposited more fine material upon it, so that we imagine it is imprisoned in more or less excellent condition. The days, the weeks and the months go by. The deposition process has continued and much fine mud has been laid over where the animal lay. Its prison has become stronger and more secure. Then the years go by and the centuries!

The geographical and geological changes are, however, never constant or continuous in one direction. The process of deposition

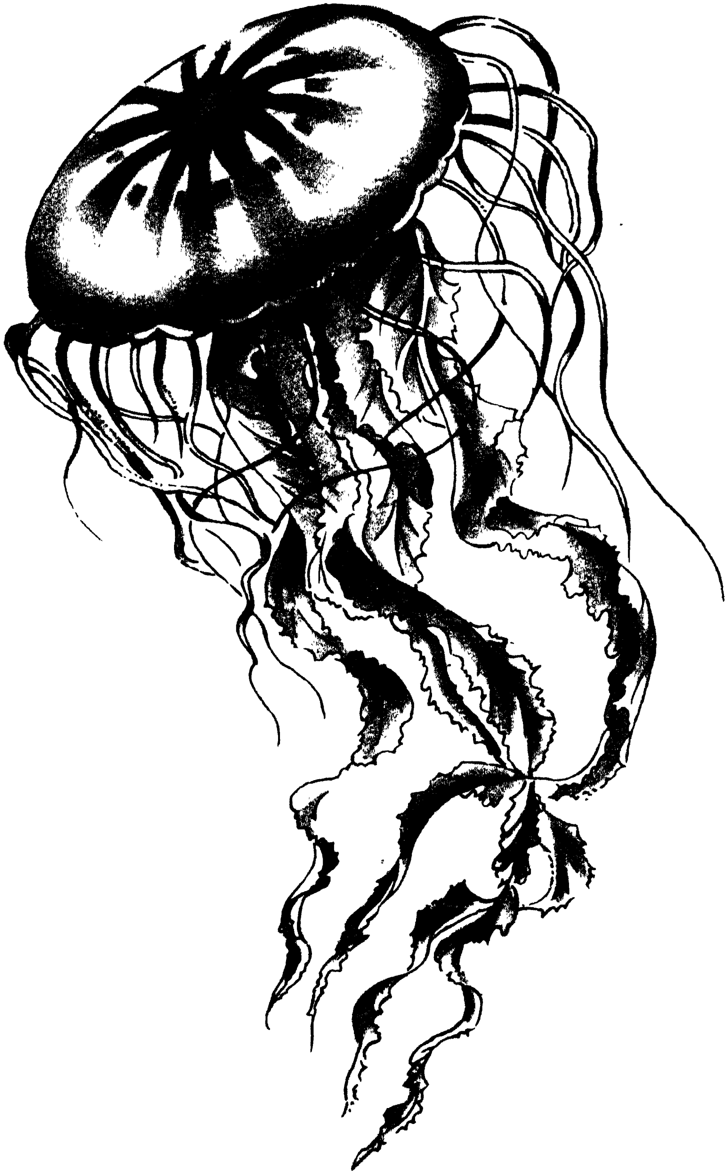


Fig. 15 CHRYSAORA MEDITERRANEA
A modern jelly-fish. Diameter about twelve inches

may have gone on, and the once thinnish mud bed is now a thick and hardened layer of rock. But there may have been changes, some flood or upheaval may have broken up the original layer and dispersed the fragments, and so the animal remains, such as they then would be and their impression, would have been lost for ever.

We will suppose that our geological prisoner has not met with any of these liberating forces; that the term of imprisonment still runs and that the walls of the prison are now thick and solid rock. In the course of the centuries this layer of hardened material may be heavily built upon by other sediments, thus exerting great pressure on the fossil. The relative movements of the earth and the climatic conditions may crack and bend them, cause molten igneous rock to be injected into them or lava to be poured over them, or have ice polish and carve them. The rocks may be elevated and attacked by frost and wind, by rain and even by the sea.

The original sediment may thus be torn asunder, baked, or ground to powder. Let us still ignore all these many possibilities, multiplied and magnified by the millions of years in which they often may have occurred again and again. Let us grant this hypothetical fossil special endurance. It is now over a thousand million years old. Its once muddy deposit is now black and slaty. What are the chances that we shall ever find it?

It may be that retreat of the waters or uprising of the land has brought it to our present land surface where the forces of erosion have attacked it and laid bare the prisoner. Or it may have been uncovered in a quarry or railway cutting, or by the process of road making, or in any other man-made excavation. Even if it is now uncovered, it will have to be found and noticed by someone who appreciates its nature.

The amount of chance in all this, chance of preservation in recognizable form after hundreds of millions of years, chance of recovery from the rocks, and chance of discovery by someone who realizes its nature and value, is so great, so overwhelming, that it is no wonder that in the history of life the pre-Cambrian is almost a complete blank. Yet it is not a complete blank, for the occurrence of phosphatic nodules and carbonaceous patches in some rocks

indicates the possibility of the altered remains being preserved, though now unrecognizable, and there are occasionally found beds of what appear to have been deposits of blue-green algae.

The whole immense period of the pre-Cambrian has so far produced to ardent and experienced collectors only a jelly-fish, a few marine worm casts, and some sponge spicules and seaweeds. Perhaps the most remarkable example of the preservation of such things is from the slaty shale of Mount Wapta in the Mt. St. Stephen region, British Columbia. This is of mid-Cambrian, not pre-Cambrian age, but there are preserved recognizable, though only carbonized, impressions of some hundred kinds of seaweeds, soft-bodied marine worms, sponges and a variety of primitive forms of higher types.

If we regard the history of life as seen in the fossil record as a film it would have to be considerably speeded up to be endured, for even if we measure its speed not at 90 feet per minute (i.e. the cinema rate) but as *one million years per minute*, it will still take over twenty-four hours to show. It would not, however, be worth your while staying all through the performance, for half of the time would be devoted to the over-exposed, over-scratched and almost totally illegible record of the pre-Cambrian. Whatever was going on in the seas, how the simple-unicellular primal forms of life were developed into the varied, complex fauna we must infer had existed during it for many centuries, we shall probably never know.

What we can say with certainty is that the forms of life were all marine. Throughout this great segment of the earth's history there was no tree, no shrub or flower or grass, and no animal of any kind on the dry land. The desolate and barren lands were the sombre but ever-changing background to the populous seas where this long-drawn-out overture to Life was played.

CHAPTER VII

ANIMALS WITH SHELLS

If we had been able to look at the Cambrian world we should have found it a very different place from that we now know, with an entirely different arrangement of the lands and seas. The lands were temporarily more extensive and the seas more restricted. The climate over the period was moderate to cool but probably on the whole not quite so genial as it is now. But the principal feature that would impress a modern observer would be the barrenness of the lands. There were no trees, shrubs, flowers or grasses. Near the shores there may have been some green, grey or yellowish fungi parasitic on the algae and covering some of the rocks rather in the manner of modern lichens, but there were no tuberous or rooted plants. There were, of course, no animals of any kind in the air or on the land for none was as yet capable of breathing air. In the seas, however, things were vastly different. Here was a multitude of forms in great variety, for the long and dark ages of pre-Cambrian development had brought forth their creations and invertebrate life was having its *première*. We are well aware of the constituents of this fauna and our knowledge and the evidence for it are richer beyond comparison with those of the years before. The reason is that most of the Cambrian animals had shells, and shells can be preserved. When we say we know the life of the Cambrian (and later formations) so well we are not, in fact, speaking the literal truth. We know the houses of the inhabitants so well and imagination and the comparison with living forms tell us most of what we know about the things that actually lived in those houses of lime or chitin.

Why did the Cambrian inhabitants develop shells? No one can say. It is a mystery at which we can only guess, but several theories have been put forward to explain it.

Whatever the cause may have been it is clear that the de-

velopment would not be sudden. There must have been a long period of trial and error so that the final adoption of armour is only apparently a sudden change from the pre-Cambrian conditions. The suggestion has been made that the earlier forms were free-swimming or floated on the surface of the water, but that shortly before the opening of the Cambrian period some of them began to live on the bottom of the shallower waters. Here there would be an abundance of food and room to increase in numbers. These bottom-dwellers would thus tend to multiply and competition for living space would eventually be acute in some areas. Thus attack and defence would be common and the need for armour would arise.

Fig. 16 NUMMULITES ORBICULATUS
Median section showing septa. These coin-like fossils were great rock builders in the later geological periods

On the other hand, several writers have suggested that there was insufficient lime in the waters in the earlier period to permit animals to develop shells and that the shells were produced only as the increase of lime took place through the wearing away of rocks. There is, however, evidence that makes this theory not entirely satisfactory.

Still another suggestion is that the pre-Cambrian forms were vegetarians and that they lived fairly happily together without undue competition. Then, by chance, one group may have acquired a taste for its fellow creatures, and cannibalism developed. The cannibal group would increase enormously at the expense of the helpless vegetarians, until the latter developed some form of protection for themselves. The utilization of the limy waters to make skeletons and shells may have been the only possible answer. If this were so, how many kinds of animals were destroyed before the successful defensive stage was reached we shall never know,

and we shall probably never find out who the villains in this early drama were. It has been suggested that the Trilobites may have been to blame. This appears rather doubtful for they are well armoured themselves and in nature it is seldom the attackers who bear the heavy armour. However that may be, we shall see that even the Trilobites came in for some heavy treatment later on.

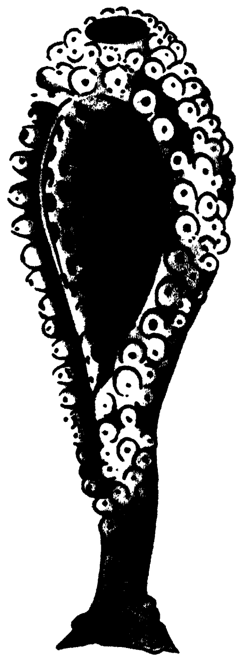


Fig. 17 SYCETTA PRIMITIVA
A sponge from S. Australian waters.
One sixth of an inch high.

There is, however, much to be said for a theory of a very different nature, that is, that the development of an external skeleton was a matter over which the animal had no control, and that it was, and is, primarily a chemical process. In the lowest forms of life this skeleton, or series of spicules, is siliceous or calcareous, and the skeleton is developed and persists even where it is of no obvious advantage to the unicellular animal. In the higher invertebrates the skeleton, which is external, is often composed of calcium carbonate. It is reasonable to presume that since calcium is present in the waters in which these animals lived, and is often present also in their food substances, that in solution it may have penetrated to the very cells of the animal. From these it would be excreted and the ultimate amount that would adhere or be lost would be determined by the vital activity—the metabolism—of the animal. The same applies to the excretion of horn or chitin and a glance at the animal kingdom will show that it is notoriously the most static of animals in which the skeleton is most developed.

We shall have to return to this metabolic theory in a later chapter.

Once started, this development of shell and similar defensive and body-strengthening materials went on, and in the Cambrian and succeeding periods there were great groups of many different kinds of animals living in their shelly homes. The structure of these varies greatly. Some are amazingly beautiful, some are grotesque, and others are remarkable for their size and complexity.

Immense numbers of Radiolaria and Foraminifera have been discovered as fossils and very many of them have been described. These are simple animals, belonging to the Protozoa and thus related closely to the primitive animals discussed in previous pages. They hardly need description here since they still survive and the early forms are quite similar to the recent. Many of them had naked bodies but some had a fine, often beautiful shell, or 'test' as it is sometimes called, of delicate construction, so that they were not suitable for preservation in the older rocks.

The Foraminifera were thus relatively scarce in the earlier periods but they became very abundant in the Carboniferous and later deposits, and they have attained a special place in scientific studies because they were common in many places during the formation of oil-bearing strata. They are thus of great interest and importance to all who have to search for, and exploit, oil deposits, and it is no exaggeration to say that today several hundreds of persons are engaged in the study and classification of these little fossils (fig. 16).

Another group of animals from the early days that are of interest are known as the Graptolites. Today we only know them by the remains of their horny coverings that are usually seen as markings on dark shale. Their appearance is very similar to pencil markings on slate and it is from this that they get their name (Greek: *Grapho*, I write). The 'written stones' were thus dignified by the Greek name Graptoliths, which has now become Graptolites.

We can only reconstruct what their living form was by analogy, for their soft parts are quite unknown. Even the shell, though known to be of chitin, is usually modified by its long entombment and has become carbonized or even replaced by iron compounds. It has usually a branch or saw-like appearance (fig. 18).

The complete animals appear to have been like a small block of one-roomed flatlets, each flatlet being occupied by a polyp. Each polyp had a communicating tube with its neighbour and the whole chain of polyps was contained in a horny covering. The colony depended for its form on the nature of this chitinous rod-like container. Sometimes it was a single rod with all the polyps on one side; often there would be cells with their polyps on both sides, and often the rod was curved, or bent into a spiral. The whole colony of rods and their polyps was suspended in the sea by an umbrella-like float, or perhaps attached to a piece of seaweed, and on the surface of the deeper seas these colonies must have existed in great numbers. Many Graptolites may, however, have been anchored to the bottom or to rocks.

When the polyps died and decayed in their cells or flatlets the horny sheaths sank into the mud, which was hardened and pressed in the course of time into the shales and slate so characteristic, for example, of many parts of Wales. Here today can be found in the hard rocks and the high hills the altered remnants of a form once characteristic of the high seas.

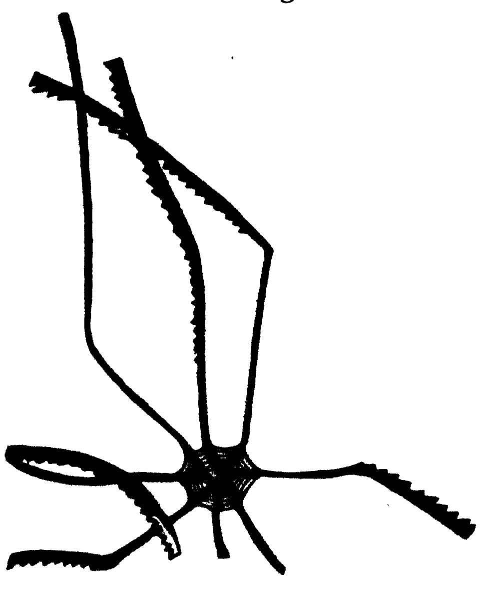


Fig. 18 DICHOGRAPTUS
An Ordovician Graptolite

Now the cell-living Graptolites were of a higher order of living things than the single-celled organisms we have so far mentioned. Between the rod-like branches and the float there can be seen in some forms reproductive sacs and here again we come to a class of animals in which different parts of the body or colony are set aside for different functions, although as yet on a comparatively simple scale.

The great group to which they belong is known as the Coelentera, from the Greek words meaning 'hollow intestine'. This name is applied to them because all the members of the group, the Hydroids (including the Graptolites), the Jelly-fishes and Sea-anemones, and the Corals, are all characterized by having only one internal cavity that opens to the outside through the mouth. The body wall surrounding this cavity is of two layers of cells and the outer layer in some of the forms has special stinging cells. The resemblance between these much larger and more complex animals and the simpler unicellular *Paramecium* will be noted in some of these general details.

Many of the present-day forms belonging to this group are well known and, as many of the fossil forms are so clearly similar in form and habit to the present types, it is hardly necessary to deal with them here.

The corals of the past, like those of the present day, formed large reefs in the warmer seas and these have now become great limestone deposits in which the abundant remains of different kinds of the coral-builders can be identified. Some of these corals were rather like a honeycomb in shape and arrangement, while others had strong tubular walls often supported by internal partitions of lime. This is just another form of house for the polyps that were much like those of the Graptolites.

At first, in the Cambrian period, the corals were not very common, but some time later, especially in what is known as the Silurian period, they were very well developed and numerous. In England their remains of this date are especially well seen in the Wenlock limestone of Shropshire. Sections through them can often be seen in marble-like stonework used for decorative purposes, though sometimes these markings are faked in inferior or artificial stones.

The delicate outlines of the beautiful and large jelly-fish, which are related to the corals, could hardly be expected to be preserved as fossils since they have no hard skeleton, but actual imprints have been found in the Cambrian rocks of Sweden, Canada and the United States.

Fig. 19 PENTACRINUS
A Jurassic crinoid that attached itself to floating objects. Seven feet high

From those early days the remains of another comparatively lowly type of life are also found, those of the sponges (fig. 17). Spicules as well as the remains of stony-walled sponges have been found.

Still another group, the Echinoderms, now familiar to us as star-fishes, sea-lilies, sea-cucumbers and sea-urchins, was but feebly developed in early Cambrian times, and its only representative in these days were the small forms on stalks, known as Cystids, which are not living today. But later, especially in the deposits at the closing days of the Cambrian, there were appearing in increasing number their relatives, the Crinoids.

In this country they are first found in what are known as the Tremadoc beds of that district in Wales, and although at this late Cambrian stage they are not very numerous, they were to become so later, especially in the Silurian (Wenlock limestone) and in the Carboniferous limestone.

The Crinoids include animals that are perhaps better known as the sea-lilies and the feather stars. The former are characterized by having a stem which attaches them to the sea floor or to a rock in the sea. At the upper end of this stem is a roundish or, sometimes, a cup-shaped body, known as the calyx, that contains the organs of most importance, including the digestive system, its entrance (the mouth), and its termination (the anus). Surrounding this calyx are usually five movable arms that arise from its outer rim. Although there are, as has been said, usually five arms, these may branch and each branch may give off a number of unbranched pinnules which give the whole animal a very plant-like appearance (fig. 19).

The stem may be circular, elliptical, pentagonal or quadrilateral, and it is composed of a large number of little plates placed one on top of the other. This stem so formed may be short or it may be several feet long, but it is flexible. At its base it is usually branched, like a plant, to form a holding 'root' for the animal in the material on the sea floor. The centres of the plates forming the stem are pierced by a little hole so that the whole stem is hollow and this cavity contains a branch of the nervous system and of the water-circulating system.

The calyx at the head of the stem, with the mouth and anus, is a complex structure with well-developed nervous and water-circulating systems.

The five arms, and their branches, have grooves on their inner surfaces, and these grooves, known as food-grooves, run down not only the arms but over the calyx to the mouth. The grooves are lined by cilia, those hair-like vibrating oars that we have mentioned before for locomotion. Here their task is to move the food supply — that is, the sea water with the minute animals on which the Crinoids feed — in a continuous flow to the mouth.

The general structure of a Crinoid is of course very much more

complex than this. The arrangement of the plates, the circulating system, the nervous system, and the whole process of living and feeding are obviously on a higher level than those we have so far been considering, and we have not dealt with the muscular and reproductive elements. These Crinoids enjoyed a high status in the early days of the Palaeozoic and were so numerous in the Silurian period that it has been called 'The Age of Sea-Lilies'.

They must have made an impressive and quite beautiful sight, for their fossilized remains, recovered from some limestone that they helped to build, are often wonderfully attractive. Today they are fewer in number and though often they live at great depths in the sea they are not infrequently drawn up by a trawl.

The related Echinoderms — the sea-urchins and the star-fish and brittlestars — of the Palaeozoic were not so numerous as they became in much later geological days, but as they are still commonly found and are well known we need not dwell upon their structure here. We shall have, however, to refer to them again in the next chapter.

One of the most important classes of the shelled creatures is the Mollusca, especially those known as the Cephalopoda, which include entirely marine forms, the cuttle-fishes, squids, and the *Nautilus*, and the extinct forms known as Goniatites, Ammonites, and the Belemnites.

The Cephalopoda are distinguished by the circle of arm-like processes that are given off around the mouth. The arrangement is somewhat like, but has no real relationship with, that we have just seen in the Crinoids. Here the processes are fleshy and have no cilia, but have either little sucking-plates or tentacles to catch and pass the food to the mouth. These arms and tentacles around the mouth and head are considered by zoologists to be derived from the fore part of the 'foot' of the ordinary mollusc (shell-fish) and so the group has become known as the Cephalopoda or 'head-foot'.

The Molluscan foot is, of course, the well-developed muscular body on which we now see the land-living forms crawl along the garden path. This much we all know, but many do not perhaps realize the increasing complexity of the whole organism. Above

the foot is the body, which in many molluscs is bilaterally symmetrical. There is a mouth at the front end and a nervous system close to the mouth but with branches to various parts of the body. There is a well-developed heart and kidney-like organs. Above the body is a *mantle*, a fold of the skin that not only covers and protects the gills by which the water-living molluscs breathe, but always secretes the material of which the shell is made.

Now even a little experience will enable us to observe that the habits of the Mollusca and the forms of their shell vary widely. There are the types with two more or less equal halves enclosing the mollusc as in the razor shell, the mussel and the oyster, and there is the coiled shell like that of the snail. Many of the Cephalopods, especially of the fossil forms, live or lived within a different sort of shell and with their head and arms outside.

Today, although many of the Mollusca are still marine, there are even more which live in fresh water or upon the land. In the geological periods of which we are now writing, however, the forms were marine and developed a series of shells that were remarkable for their size and complexity.

To explain this series we may begin with the *Nautilus*. This word is the Greek term for a sailor but was also used for the Paper Nautilus mollusc (*Argonauta*) on account of its sail-like arms with which the Greeks were familiar, and later became transferred to the Pearly Nautilus (*Nautilus*) itself.

The genus *Nautilus* is the sole modern representative of this kind of Cephalopod although in the early geological periods they were very common. Thus, although we are familiar with the remains of shells and horny jaws from fossils, for a complete picture of the animal itself, in its fleshy and living state, we must go to this modern survivor.

The anatomical structure is fairly close to that which has already been outlined for the Mollusca, but around the mouth, and developed from the margin of the head, are lobes, the arm-like processes which in this particular case have no suckers but have tentacles that can be withdrawn into sheaths. The eyes are comparatively simple when compared with other Cephalopods and with the higher forms

of life, for each consists of a hollow body or chamber with a tiny opening. There is no lens to this eye.

This animal lives in a multi-chambered shell, as we shall see, but occupying only the outer chamber. When it withdraws into its shell, it covers up the opening with a 'hood' formed from a special enlargement of the outer lobe of the foot.

The shell is often lustrous and beautiful, and although in the present-day *Nautilus* it is large and coiled, in the period of their greatest development some of the Nautiloids and their relations had shells that were straight, or merely arched, or coiled or even spiral. However they may be finally shaped their formation is approximately the same.

The shell in the Nautiloids and in the Ammonites, their extinct relatives, is always external, that is, it has been lived in during

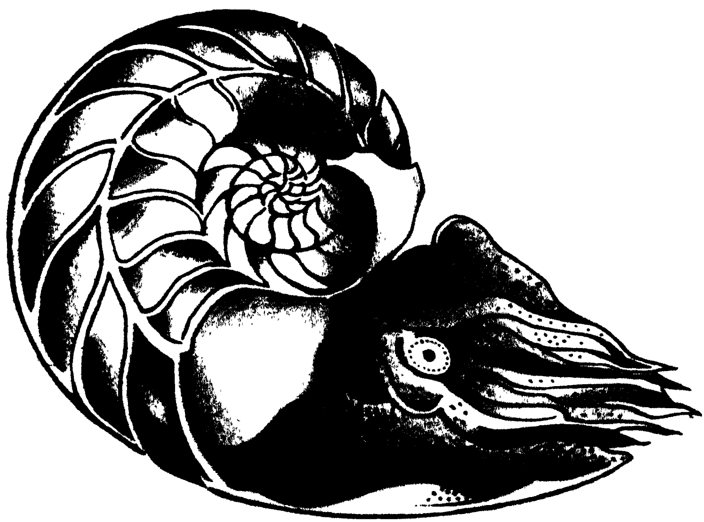


Fig. 20 NAUTILUS POMPILIUS
The living Pearly Nautilus. Diameter about five inches

Fig. 21 PTYCHITIS OPULENTUS

A Lower Triassic ammonite, showing the characteristic suture lines

life by the Cephalopod. We may start with the small young mollusc and its little shell which is, as we have said, secreted by the mantle. After a period of development the mollusc becomes too big for its shell — so the mantle adds a bit to the free side walls, thus raising them, and, in addition, it secretes a layer of calcareous (nacreous) material behind it so that the first part of the shell, the primitive single room, becomes shut off by this partition wall from the new and slightly larger chamber. This first 'living room' has on its inside, in the Ammonites, the mark of the embryonic shell or protoconch.

As this process goes on, with continued growth and the consequent enlargement of the shell opening, with the formation of dividing walls, which we call septa, at progressive distances, one in front of the other, the resulting form, were it in a straight line, would be tube-shaped, like an elongated trumpet. We may consider that this form might not be economic, that space was being wasted, and with some forms Nature apparently thought so too, so that though in the early days of geological history there were many quite large and straight or slightly curved shells, other forms speedily took up a coiled form. In size these shells vary from quite small and coin-like forms to others several feet in diameter.

In the Nautiloids the vacated chambers, the old homes of the animal, were filled with a gas, which increased the buoyancy of the animals, but the chambers were not entirely forgotten. The hind end of the mollusc's body had a long thin 'tail' containing arteries and this passed right back to the chamber immediately in front of the protoconch. This tail was enclosed in a thin or occasionally a thick calcareous tube, known as the siphuncle, which in *Nautilus* itself is in the centre, but in the Ammonites is usually near a margin, of the partitions (septa) between the chambers.

There is evidence that closely connects the Nautiloids and the Ammonoids although the soft parts of the latter are quite unknown, but one important external difference must be mentioned. In the Nautiloids the form of the septum is comparatively flat and with a comparatively simple connection (suture) between it and the outer wall of the shell. In the Ammonoids, and more especially in the

later ones, this sutural line is far from simple but may be of very complex pattern (see figs. 20 and 21). This complex suture strengthened the outer wall of the shell but in palaeontology its form is a help in identification and classification.

It will be realized from this brief account of the group that there is much to study if we are to attempt to understand properly the living organisms associated with these shells. Visitors to Dorset and to the Yorkshire coasts will be familiar with the coiled shells so frequently found there. These shells are serpent-like, but the likeness is quite often accentuated by the carved alterations of the fossil seller.

All these Ammonoid and Nautiloid forms are classed together as having, or as being presumed to have had, four gills. There is, however, an allied group with two gills that comprises the cuttle-fishes, squids and octopuses. They are not nearly so important geologically as the others, apart from one kind known as the Belemnites. The remains of these last, which are quite frequently found, and which look like smallish projectiles, vary in shape, and in size are from an inch to eighteen inches in length, some being largely cylindrical and others conical, but one end is always pointed. This is what is technically known as 'the guard' and is part of the *internal* shell that supported the animal's body. At the other end of the shell is a deep depression. Occasional specimens have been found with the impression of the body still visible upon them and from these specimens, and by comparison with other forms, we know that they were quite like the modern squids (fig. 22) and even possessed an ink-sac. The inky fluid in this sac could be ejected into the surrounding water, thus making it cloudy, so that the Belemnite (like its modern counterparts) escaped from the animals pursuing it. This is the primitive natural equivalent to the man-made smoke screen.

Some of these forms were quite large, but not so large as some modern cuttlefish, which grow to forty feet or more in total length.

The Belemnites come later in geological history than the Ammonites and their shells have often been misinterpreted in the past.

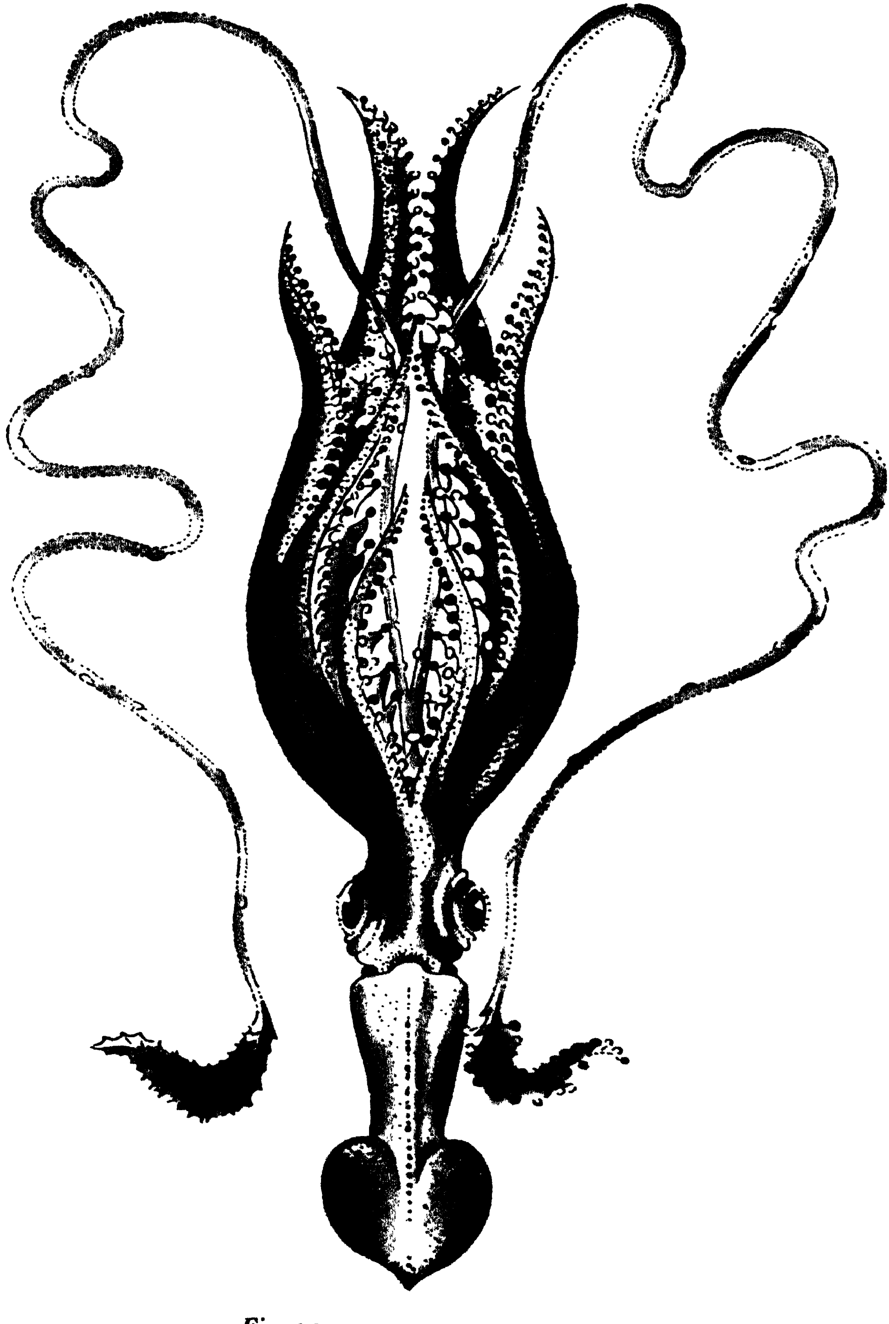


Fig. 22 CHIROTEUTHIS VERANYI
A modern squid

Even at the present time they are not infrequently sent to museums by people who think them to be thunderbolts.

We can hardly leave the Mollusca without mentioning a remarkable shell that was discovered some years ago in Alexandra Park, Hastings. To be strictly accurate it must be recorded that only fragments of two spiral bodies were found. One was coiled in a right-handed spiral and the other in a left-handed spiral. The fragments give some indication of the original form, and when they were reconstructed in plaster the resulting form was no less than seven feet long, though this may have been a slight exaggeration. The remains have been described in scientific literature as a fossil shell under the name of *Dinocochlea*, or huge shell, but it has remained a much-debated point as to whether it is in fact a shell or just a very curiously coiled concretion. Whether fossil or concretion, its two variations, right- and left-handed, and its mode of origin, provide material for discussion (fig. 23).

Along with the molluscs there were developed other shelly creatures known as the Brachiopods, or more commonly the 'lamp-shells'. This latter name has been given to them on account of theii close similarity in appearance to the old Roman lamp.

Like many of the molluscs they have survived until today so that their structure and appearance are well known.

On an earlier page it was said that the incentive to the development of shells may have been the appearance of a predacious kind of animal — the early geological gangster — and it was suggested that this may have been an early Cambrian form that became well developed and widespread, and is quite well known, under the name of Trilobite, to palaeontologists.

The Trilobites form one of the most characteristic types of life of the earlier geological periods. They are very common, but the suggestion that they may have lived in the seas in vast numbers must be tempered by the thought that their hard covering of chitin, from the head to the tail, has rendered them from the very beginning of the Cambrian as especially suitable for preservation.

Trilobites have long been extinct for they did not survive the Palaeozoic era. They were distantly related to the crabs and the

lobsters and they had a very characteristic oval and flattened body (fig. 24). The head of the Trilobite was covered by a shield of chitin and towards the edge of each side of this shield was a faint fold in which the eye was usually placed. The eyes were not unlike those of an insect, for they were compound and contained a large number of lenses. In one later Palaeozoic Trilobite the number of lenses is said to have been so many as 15,000. Not all of them were so well supplied visually, and some of the early Cambrian forms were blind.

The back of the body was also protected by a covering — or carapace — of chitinous material. This body was in transverse segments and there were also lines or furrows, one on each side, running backwards from the head to the tail, dividing the body therefore into three longitudinal parts or lobes, hence the name tri-lobe-ite. On the underside of the body it can sometimes be seen that each of the transverse segments had a pair of double legs. Each leg consisted of an outer and an inner branch. One branch was used for crawling on the sea floor and the other was more adapted for swimming in the water.

Behind the body was the tail, a stiff shield of chitin in which the segments are fused. Thus, laterally, there were three lobes, and

Fig. 23 DINOCOCHLEA INGENS
A remarkable fossil shell from Hastings, seven feet long

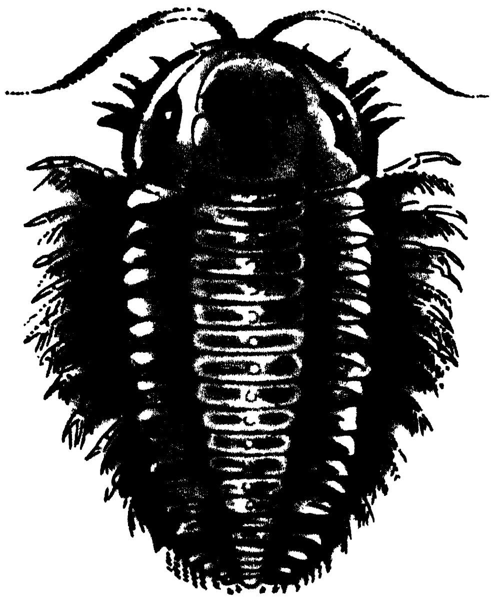


Fig. 24 TRIARTHRUS BECKI
An Ordovician trilobite from New York State. Actual size about four inches

fore and aft there were three divisions: the head with eyes and a pair of antennae or feelers and the jaws; the jointed body or thorax, with as many legs as some centipedes; and the hind tail shield. The thoracic segments allowed the animal to roll up until the tail and the head came together.

Trilobites were small, usually only an inch or two long, although some of the largest forms approached two feet. They were obviously adapted for life on the sea floor, most of them being able to burrow in the mud and sand in search of food, but perhaps others floated at the surface of the water.

There were other Arthropods living in these early Palaeozoic days also, though they were not present in the Cambrian. For example there were the Ostracods, tiny two-shelled creatures that were often in great numbers and whose representatives survive to the present day.

In conclusion we may mention briefly another group of the highest of the shelled representatives in the zoological sense. The Trilobites and these others we have just mentioned are Arthropods

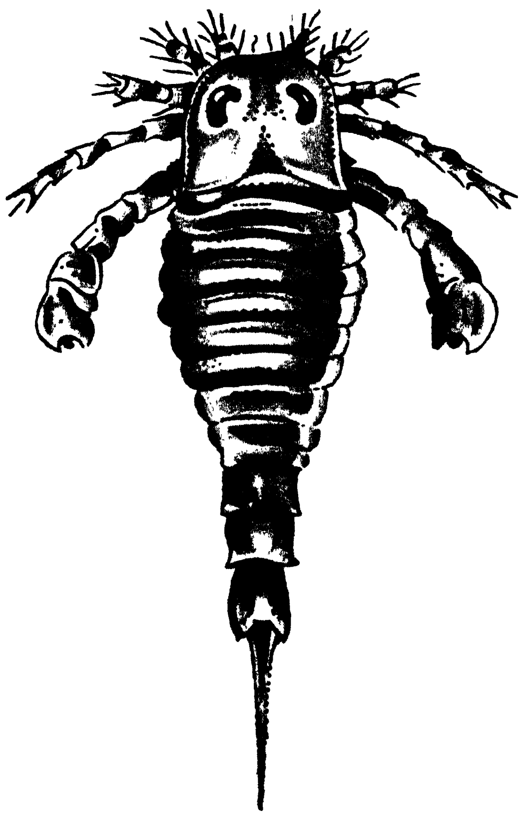


Fig. 25 EURYPTERUS FISCHERI
An Upper Silurian Arachnid, about three feet long

('jointed feet'), and so also are the Arachnida ('spider-kind'), comprising the spiders and scorpions, which were represented in the early Palaeozoic by the Eurypterids ('broad-finned'). They were jointed (i.e. segmented) creatures, rather like scorpions in appearance and very much like them in their arrangement of parts, but they were all marine and are thus known generally as the sea-scorpions (figs. 25 and 26).

They were restricted to the Palaeozoic, first coming into the geological scene in the Cambrian, being widespread during the formation of the Old Red Sandstone, and finally dying out in the Permian (see Calendar of Life). They were great creatures for their time, sometimes being six feet long, and they preyed upon their smaller neighbours, Trilobites and the like.

These diverse forms, beginning with the simple unicellular animal in a shell, and proceeding upwards to the complex forms with elaborate shells or chitinous coverings, and with definitely assigned functions to parts such as eyes, heart, blood and nervous systems, and with well-developed limbs, impressive as they are, were still but in the prologue of life.

For at least the first half of the Palaeozoic era's 400 million years, i.e. up to the end of the Silurian, there were no important animals on or over the land, and for most of that time the living forms were all marine. They were creatures of the sea, although doubtless, as we shall see, some, like the worms and some small shell-fish, were accustomed to live on the shores for brief periods.

The seas were teeming, but the lands, approximately as extensive in the Silurian as now, were tenantless. The marine creatures had more in common than the nature of their habitat. Those we have discussed in this chapter had shells, shells of lime or chitin or silica. Sometimes, as we have seen, that shell was inside (as in the squids), but mostly it was a protective covering, a home, for the animal. But none of these many animals had developed a bone, none had a skeleton, as we understand it. They are all together in what is classed as the lower half of living things — the Invertebrates, or backboneless animals.

Geological history shows us that the greatest advances, biologic-

ally and territorially, were to be made by the animals with backbones, the Vertebrates. How did they arise and how do we account for the great transition: the change from invertebrate forms to animals with backbones and supported limbs?

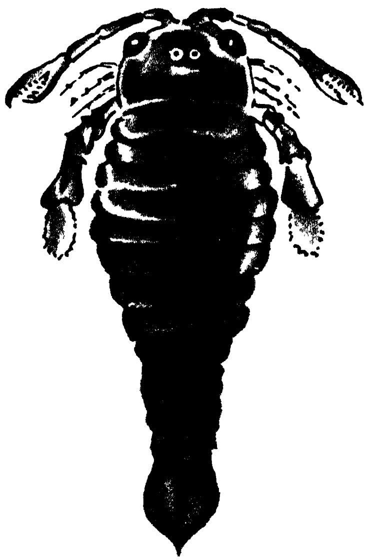


Fig. 26 PTERYGOTUS ANGLICUS
An enormous Arachnid, from the Old Red Sandstone, which was sometimes six feet long

CHAPTER VIII

THE GREAT TRANSITION

It is perhaps a little confusing to break the narrative at this point. In time we have been in the Silurian, some four hundred millions of years ago. We have reached a high point in the development of the invertebrate faunas, but not the highest point, for many of them have continued until today, so that their evolution has gone on as well as that of the geologically younger vertebrates.

If we accept the derivation of the vertebrates from the invertebrates as inevitable, that derivation was, therefore, a branch of the evolutionary tree and not a continuation of a single progressive stem.

The vertebrates are of paramount importance because obviously the most complex and highly developed animals are included amongst them. Man is a vertebrate, as are his domesticated companions, the dog, cat, horse, sheep and the oxen. His food is largely of vertebrate origin: beef, mutton, cheese, milk, fish, and even, in these days, whale meat. His sport is vertebrate too, for he angles for fishes, shoots birds and rabbits, stalks deer or, less energetically, watches the competitive efforts of greyhounds or horses.

These are all major figures or pastimes in man's life. Apart from the pleasures, restricted by taste or cost, he may take in shell-fish as food, his chief contacts with invertebrates are when he destroys the garden snails, or protects himself against the nuisance of insects and the insidious attack of protozoa or bacilli, or goes in for bee-keeping.

There are, of course, exceptions, and many people have developed an interest in groups of invertebrates but, generally speaking, the backboned animals play by far the largest part in human life, and we have, equally clearly, a much greater knowledge of them. From the scientific point of view this last fact is soon borne out by even

a cursory glance at a comparative anatomy book, for there one will see that anatomical nomenclature was first worked out for man, and the terms have since been transferred to, and transposed for, the vertebrate forms which are regarded as lower or simpler than man's evolutionary level.

In explaining even briefly the characters included in the term vertebrate it will thus be necessary here to start from the known and move to the unknown, to go backwards along part of the evolutionary road. If working backwards seems to be wrong technique, at least it has its parallel in literature, for it is the usual method of detective fiction, and we have already likened the methods of palaeontological study to those of detection.

Amongst the characters of the vertebrates we see that a skeleton is an essential; but we have already noted many forms of invertebrates, both of lowly and higher origin, that had skeletons. Invertebrate skeletons are, however, of silica, calcium carbonate or chitin (a substance usually excreted and allied to uric acid), but vertebrate skeletons are of bone or cartilage, two tissues that are closely alike except that where cartilage is comparatively soft and resilient, bone is hardened by the deposits in it of the carbonate and phosphate of calcium. Cartilage persists even in the adult human body, but in general it tends to precede, and to give way to, the development of bone in skeletal growth.

Every adult is aware that in his body, in all strategic positions, he has a well-developed bony protection. The skull is obvious, and the long series of knobbly vertebrae, from the skull to the 'tail', can be felt. The arms are supported by a series of long bones in the upper arm and forearm with a complex of little bones at the wrist and with shorter bones in the palm of the hands and in the fingers. The chest is almost completely, and the sides of the abdomen partly, protected by bony and cartilaginous ribs. The legs have a series of long and short bones closely similar in arrangement to those of the arms, and at the top of the thighs, joined with the thigh bones and helping to maintain a balanced system, is the pelvic girdle, a series of fused bones that also lend support to the viscera, or abdominal contents.

This is, in briefest outline, an obvious picture of the human skeleton.

Comparative observations on the common domestic animals, and even an elementary experience in the preparation of the meat we eat, will show that these animals are supported in a very similar way.

The familiar process of dissecting a kipper or a herring at the breakfast table shows that these fish have a different skeletal system, presumably modified to meet their different mechanical problems in a different medium of life, but none will deny that their skeleton is important or well developed.

But however variously developed the skeleton may be, it is also clear that these animal groups, the fish, the amphibia, reptiles, birds and mammals are united, not in being called 'skeletonates', but in being vertebrates. That is, they are named from the Latin word *vertebratus* or jointed, because they have a series of joints, or vertebrae, in the backbone. They are all backboned animals, they all have what we rather loosely call a 'spine' in the human being.

Figure 31 shows the front view, that is, the headward side of a vertebra. It is not that of a human being, but it is a bone from the hinder part of the neck of a large extinct reptile with which we must deal later. A comparable vertebra of a human being would measure two inches, but that of the reptile vertebra measures in the original skeleton three and three-quarter inches from the base to the top of the spinous process.

The lower part of the vertebra consists of a solid barrel of bone, very similar to the wooden core of a cotton reel, except that it is solid, and this is called the centrum. Above the centrum is an arch with bony buttresses terminating in a blunt ridge, the neural spine. In the human being the ends of the spines can be felt by running the finger down the centre of the back. This arch above the centrum, with its processes and spine, is known as the neural arch, and between it and the centrum, and clearly shown in the figure, is a more or less circular tunnel, the neural canal or opening for the central nerve cord that in all the familiar vertebrates connects the hind end of the brain with the hind, or lower, end of the vertebral

column, and by its nervous branches controls most of the body movements and functions. It is variously called the nerve cord, part of the central nervous system and, in human beings, the spinal cord. If it is severed, or if the vertebrae are displaced or damaged so that they press too hardly upon it, then all the limbs and organs, at least below the injury, will be paralysed. Such paralysis is all too common, unfortunately, among the disabled victims of war.

Now, this central cord is present in all the vertebrate animals we have so far mentioned in this chapter, and its presence helps us to understand even more clearly the importance of the vertebral column, as the backbone is called. This column gives support to the animal, and, by the attachment of muscles to the spines and buttresses of the vertebrae, it assists in the elasticity of the animal's movement and the series of jointed vertebrae is thus either rigid or flexible as desired. But the vertebral series also lends strong bony protection to the vital nerve supply between the brain, in the bony skull, and all the other parts of the animal.

We have, therefore, arrived at the fundamental importance of a central nervous system in a highly efficient animal mechanism. We started with a brief consideration of the skeleton, which led to

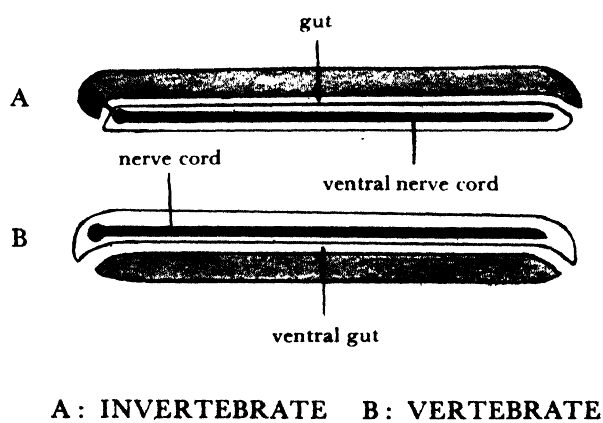


Fig. 27 THE RELATIVE POSITIONS OF THE INVERTEBRATE AND VERTEBRATE NERVE CORD

the vertebral arrangements, which in turn lead to the central cord.

Already in this chapter we have apparently divided animal life into two great groups: the invertebrates, and the vertebrates, and this is a common enough grouping. It is not, nevertheless, the strictly zoological classification. Zoologists regard the great group of the vertebrates, with some other forms that we must mention, merely as a *phylum* (Greek: *phulon*, a race) equivalent to the phylum Mollusca, phylum Arthropoda, phylum Protozoa, and others we have mentioned in earlier chapters.

This phylum containing the vertebrates is called the Chordata, and it is characterized by all its members having, at one time or another in their lives, a smooth and elastic rod known as the notochord, a term coined from Greek words meaning a 'back string', as this primitive axis really is.

In the higher forms of the phylum this chord becomes invested, and ultimately destroyed, by the vertebral column, so if we are to understand the transition of an invertebrate form to a vertebrate, it is among the types with a notochord that we must search. We must study this chord and its relations with the developing nerve cord.

There is one other fundamental arrangement that appears to be characteristic of the chordates and that is the relationship of the internal cavity (oesophagus, gut, etc.), the notochord or backbone, and the nerve cord or spinal cord.

If we ourselves lie prone upon the floor we can exemplify the characteristic relationship, for our internal cavity is nearest to the floor, above it is our backbone and, immediately in and above that, is the spinal cord. This is the position in all the other vertebrate animals that we can examine, but in the comparable invertebrates we find another state of affairs. There, of course, the backbone, or a notochord, is absent, but the internal cavity or gut is towards the upper side of the prone or horizontal animal while the nerve cord is near the ground, i.e. ventral, in position (fig. 27).

Bearing these things in mind, if we turn our attention to the lower chordates we find several interesting forms. One of the most commonly discussed of these is the little fish-like *Amphioxus* (Greek:

sharp at both ends), known also as the lancelet. Both of these names are given to it because of its comparatively long and flattened shape and because it is pointed at both ends. The adult lancelet is about two inches long and is translucent, and it burrows in the sand either at its head end or at the tail. At night it swims actively, but on account of its shape it tends to fall on its side when it stops swimming. If it takes fright it immediately burrows in the sand.

Now *Amphioxus* has no bones or cartilage of any kind in its back, and it has no teeth or jaws; it has a cartilaginous ring supporting its mouth and its lips have rods with cilia, which produce a current of water that washes into the mouth the small organisms that are its food. It does, however, have a long notochord, consisting of largely gelatinous cells encased in a firm sheath. Furthermore, this has above it a nerve cord running the length of the animal and below them both is the well-developed and quite complex alimentary canal. There are numerous internal gills which communicate with the exterior and there are special arrangements to ensure that they do not become choked by the silt in which the animal lives.

Amphioxus is a member of a group known as the Cephalochordata, or head-stringed group, and the notochord is of very real value to the animal for its elasticity helps the continuity of its muscular swimming movements. Incidentally this form has pairs of muscles like a fish and these can be seen in the translucent body. *Amphioxus* is the simplest of the true chordates, but it is related to forms which at first sight are very different to it in appearance and habit. These are arranged in two main groups.

The first of these, the Urochordata (or 'tail strings'), includes quite a number of marine animals to be found on many rocky shores. They are perhaps better known as the Tunicates or sea-squirts. The adult sea-squirt is just about as different as it can be from *Amphioxus*, or what we think of as vertebrates. Here is no free-swimming fish-like movement, but instead a shapeless and sedentary mass sticking to rocks or weeds in shallow water. It is covered with a leathery tunic (hence the name Tunicata). Examination shows that it has no notochord and no nerve cord; it has a barrel-like stomach and a gill system. The water and the food

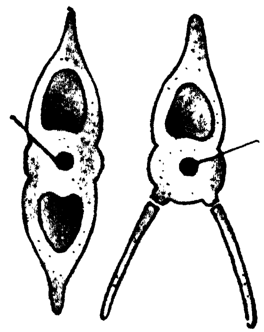


Fig. 28 FISH VERTEBRAE, SHOWING POSITION OF NOTOCHORD

organisms are drawn in by the movements of cilia at the top of the animal and the waste ejected at an opening in the side. When disturbed the animal squirts out water at both openings.

The very young Tunicate is entirely different. It is like *Amphioxus* in that it is a free-swimming little creature with a shape like a tadpole. It has a longish tail and in this tail there is not only a well-developed notochord but also a nerve cord above it (hence the name tail-string). As the embryo grows up it becomes attached to a rock and adapted to a sedentary life, so that the tail becomes lost and, with it, the notochord. The Tunicates are thus thought to be the degenerate descendants of a form that once was perhaps the ancestor of *Amphioxus* as well.

The second group, also related in some way to *Amphioxus*, is known as the Hemichordata (half-strings) on account of the short notochord they have. They are quite unlike vertebrates in appearance and are far more like worms, indeed some of them are commonly called Acorn worms. Here again, however, we must not confuse appearance with structure, nor the adult condition with that of the young embryo. The worm-like forms burrow in the mud, but there are also forms that live in a kind of tube and are sedentary. In this way both are similar in habit as well as appearance to some invertebrates.

If we examine one of the worm-like forms, we find, however, that its internal arrangements are far from worm-like. There is a head end with a dilatable proboscis, behind this is a collar region with a nerve cord and a notocord, and the interior part of the body is used, as in all vertebrates, for the breathing apparatus. The gut or digestive system runs along the body to the anus at the end.

The proboscis and the collar have little channels communicating with the outside and these have cilia that keep up a stream of water to these two regions. The proboscis and collar are thus kept dilated with water and so the forward end has sufficient rigidity for burrowing.

Despite their peculiar appearance there is no doubt that these Hemichordates are at the lower end of the vertebrate scale. Yet, their embryos are quite different. Whether of the Acorn worm or of the tube-living kind, the embryo begins as a small free-swimming form that is remarkably like the larvae not of any vertebrate but of an echinoderm!

The middle part of the Echinoderm system of body cavities is called the hydroceole and it later develops into the water vascular system such as we have already briefly described. In some of the Hemichordate embryos this condition is reproduced by the collar region, where in addition there are developed outgrowths that closely resemble the Echinoderm radial canals.

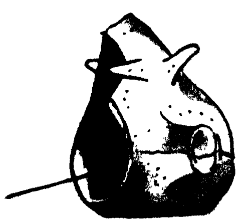


Fig. 29
PHYLLOSPONDYLOUS TYPE OF AMPHIBIAN VERTEBRA

There is no suggestion that the vertebrates are descended from the Hemichordates and that these in turn are off-shoots of the Echinoderms. But this delving back shows that there are apparent similarities between groups that are totally dissimilar in appearance and remote in present-day classification.

Appearances are notoriously deceptive, but the comparative anatomist knows that the evolutionary history of a group of animals is revealed for a fleeting moment or two in its embryonic stages.

Even the human embryo shows such traces of its ancestral past. In trying to trace back the history of the chordates we may conclude that the modern forms are probably degenerate relations of once free-swimming forms. They themselves are not ancestors. The ancestral forms, without armour or backbones, could probably not be preserved for the confirmatory evolutionary evidence of fossils, though one or two intermediate forms have actually been found.

The Echinoderms are not the ancestors of the chordates either, but what is probable is that both the Echinoderms and the chordates are derived far back in geological history from a common ancestor. Biochemistry rather unexpectedly confirms this, for certain substances are only found in all chordates and Echinoderms.

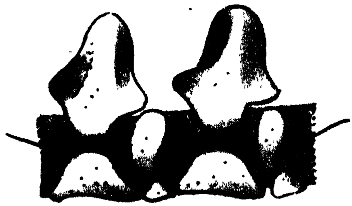


Fig. 30 RHACHITOMOUS TYPE OF AMPHIBIAN VERTEBRA

The splitting up of the invertebrate stock was an early event and what happened at the cross-roads to determine the paths that the various forms should follow cannot be known. We can surmise, however, that the Coelenterates supplied the ultimate answer: that to one road went the molluscs and the annelid worms, the shell-fish and the insects, and going our way were the round worms, the echinoderms and the primitive ancestral forms of the chordates. Today the common ancestor has long been lost and the disparity in the descendants arises because of the immensity of time spent in the journey and because, as in the human race, the children's children do not always have quite the same expression or looks, habits or manners, as did their grandparents.

Retracing the progress very briefly we see that the earliest stage probably had a more or less elastic notochord which was encased in a membranous sheath. Later in the history, as we shall see, this notochord tended to be replaced by cartilage. Then the cartilage itself at various stages in some forms, was replaced by bone. These

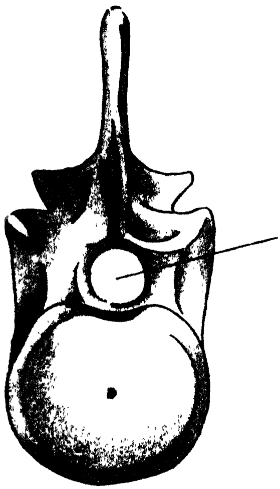


Fig. 31 FRONT VIEW OF A PLESIOSAURIAN (FOSSIL REPTILE) VERTEBRA

conditions are seen today in the fishes and the appearance of the backbone, in bony fishes at least, is familiar to all readers of these pages (fig. 28).

Some of the fossil amphibia as we shall see shortly had the cartilaginous backbone wholly or partly replaced by bone — a factor much used in the classification of them and illustrated in figs. 29 and 30. In the reptiles and early mammals the bony vertebral column has long been established, although the cartilage is never entirely lost sight of, whether it be associated with the intervertebral discs between the human vertebrae, or in the series of ribs, or in the moving surfaces of the limb joints.

The backbone in the higher forms is, however, more than the bony descendant of a far-distant notochord. It is a real piece of mechanism from the very length and direction of whose spines the anatomist can deduce much concerning the power and speed of the original animal. It is at once a clue to the history and a guide to the mode of life and progression.

The very weight and solidity of the pieces of the skeleton tell the same story as is told by the highly developed calcium-carbonate shells and plating of the sedentary invertebrates. The deposition of bone, largely the phosphate of lime, follows much the same laws as the deposition of the carbonate. Heavily developed it may defend the inactive, whose very stolidity it may have produced; lightly developed, it strengthens but does not hinder the progress of the active; run riot it heralds the extinction of them both.

CHAPTER IX

THE RISE OF THE FISHES

When we come to the rise of the fishes we are again confronted by problems, by gaps in succession and, in some instances, by apparent paradoxes. It has to be confessed once more that there is no clear evolutionary way helpfully outlined by even moderately well-preserved fossil examples. The family tree of these early vertebrates has well-developed branches, but in our reconstructions of it the main trunk has often to be represented only by broken lines.

There are many excellent and understandable geological reasons for all this. The vertebrates were most probably of freshwater origin and, as the life of the Palaeozoic has come down to us mainly through marine fossils, it is likely that the freshwater forms existed under conditions not so suitable for preservation. The earliest fishes whose remains have been found are in deposits of Upper Ordovician age in Colorado, U.S.A. As we have postulated that this was something like four hundred and twenty million years ago there are obviously great hazards in the survival of any of its more delicate fossils.

The appearance of fragments of dermal armour (i.e. armour originating in the skin) in the Upper Ordovician rocks was, in any case, only a glimpse, for in the early part of the succeeding age, the Silurian, no traces have so far been found of them, and it is not until the later, Upper Silurian, times that there is any further evidence, this time from rocks in the Baltic, from a bed composed largely of bone remains in Shropshire, and from Scotland.

The earliest fishes, though remarkable, have close resemblances to some modern forms. They are known as the Agnatha, or jawless fishes, on account of the absence of movable jaws. The mouth was supported by other external means. In addition to this absence of jaws, these fishes had no paired fins in the ordinary sense and no bony internal skeleton! So we have started with a great deal of talk about

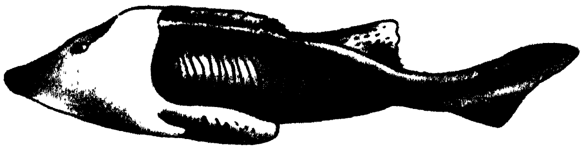


Fig. 32 CEPHALASPIS
A Lower Devonian Ostracoderm. About twelve inches long

the hypothetical development of a skeleton in the progress towards vertebrates, yet the very first vertebrate we are to describe has no developed vertebral series.

These ancient jawless fishes are a comprehensive and far-reaching group, for they include the modern hag-fishes and the lampreys, which are without scales, and the early fossil forms that were heavily and externally armoured. The gentleman who suffered from a surfeit of lampreys would have found their early relatives much less inviting.

For our purpose we may exemplify this group by the form known as *Cephalaspis* on account of its 'head shield'. This fossil fish has been known in part, from Scotland and England, for over a hundred years, yet only quite recently has its tail been found, and within the last two decades very fine examples of the fish, collected in the rocks of Spitsbergen, have enabled even minute details of its anatomy (and therefore its true kinship to the vertebrates) to be known. Not all of these specimens are of the same geological age, for the Scottish and Spitsbergen fossils are not Silurian but are from the Lower Old Red Sandstone (Devonian epoch).

Cephalaspis (fig. 32) has a large head shield, like a rounded and broad arrow-head with a backwardly projecting 'barb' on each side. This head is not very easy to describe, for in some ways a more apt likeness exists between it and the shape of some modern electric irons, if we dismantle the handle of the iron and imagine two backward flaps at the outer back edges. Instead of the backwardly emerging electric flex is a fish-shaped body covered with scales.

In the centre of the head shield, measured from side to side, and

only slightly nearer the back of it than the front, are four openings. Two of these are for the comparatively large eyes which are close together. Between them, and very slightly in front of a line joining their centres, is a small opening of which we shall have something to say in this and the next two chapters. It is the opening for the third, or pineal, eye. This so-called eye was probably in no case a true organ of vision, but it is well developed in many primitive and, often swimming, vertebrates and it may have been sensitive to light. This, the actual eye structure, was supplied by an offshoot of the pineal body of the brain, a body that not so very long ago was said to be the seat of the soul in man.

A little in front of the pineal eye in *Cephalaspis* is the opening of the nostril. The inter-relationship of these openings, or rather of the organs with which they are the outer sign, has been investigated in recent years with amazing thoroughness and skill. It has even been possible to reconstruct the size and development of the brain and the ramifications of the nerves from it. From these studies it is proved that this humble and primitive fish-like creature, with no visible means of internal support, had a brain with a primitive plan of the three typical divisions and that this brain had the ten cranial nerves that every zoological student learns from the dissection of a modern fish nearly 500 millions of years younger. Thus, once again a palaeontological paradox is seen, and *Cephalaspis*, of which we know no vertebrae, must yet be a vertebrate.

The outwardly domed upper surface of the head is covered by a series of bony plates. Underneath, an irregular series of plates covers the throat below the slit-like mouth. The actual structure and arrangement of some of these plates are curiously reminiscent of the plates of some echinoderms. Some of the areas on the head, especially along its edges, are supposed to have been associated with electric or some other kind of special sense organs to which there was a special nerve supply.

The backwardly projecting flanges at the outer edges of the head shield, the so-called cornua and the adjoining pectoral fins, were important factors in control of movement and, no doubt, elevation; for the Cephalaspid, seen from above, is remarkably like a tadpole.

Its swimming propulsion was derived from the waggling of its tapering body and tail, with the aid of the fins developed on the latter, and the speed attained would be directed to the greatest advantage by means of the forward 'vanes'.

It seems likely, if not certain, that this animal was adapted, by virtue of this heavy forward armour and the propulsion developed aft of it, for a life of scouring the stream bottoms and sucking in the mud. Forms vary in size from about four to eighteen inches. There are many somewhat similar and related forms, which, because of their armoured bodies, are known as the Ostracoderms (i.e. shelly-skins). They are a group of great interest, for quite apart from the questions of their anatomy and life history, they formed part of the delightful studies so well described in the classic pages of *The Old Red Sandstone*, written over a hundred years ago by the Scottish quarryman, Hugh Miller.

Fig. 33 PLEURACANTHUS

A Carboniferous shark with a diphycercal tail. About two and a half feet long

However well adapted these Ostracoderms were to their environment they did not long survive the days of the Old Red Sandstone, for by the end of the Devonian they had left the scene to others.

Living also in Middle and Upper Old Red Sandstone times were many diverse forms of fish apparently related in some ways to the Ostracoderms but in other ways quite distinct. Many of this heterogeneous group are placed together in a class, generally considered as a higher class, of fish-like animals known as the Placoderms ('flat skins').

They are considered to be higher in systematic position than the Ostracoderms because they have jaws and their brain is organized on a more truly modern fish-like plan.

For convenience here they may be roughly divided into three groups: The Antiarchs; the Arthrodires and the Acanthodii.

The Antiarchs were apparently widely distributed in Middle and Upper Old Red Sandstone times, for their remains have been discovered in such diverse places as Australia and Greenland. They had a head shield and the front part of the body was encased in a bony box, but behind this was a body of fish-like shape which had scales in some forms but was scaleless in others. They had little plate-like jaws, and there were paddle-like pectoral fins but, apparently, no hind fins.

Some excellent remains of them have been found which show no

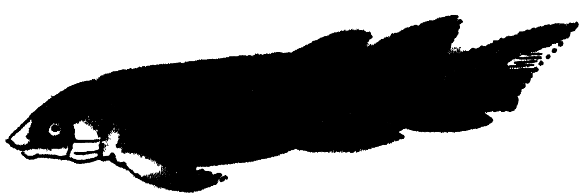


Fig. 34 DIPTERUS
A *Ceratodus*-like fish from the Middle Old Red Sandstone. Length about fourteen inches

gill-arches (to support the gills that were present), no notochordal sheath and no vertebrae. In some there appear to be impressions of lung-like structures.

They were all comparatively small in size and can have been but poor nibblers of their food.

In the next group, the Arthrodires (or 'joint-necks') several interesting developments are seen. Their armour, which is something like that of the Antiarchs, is less complete and the head is hinged to the body by a remarkable series of ball-and-socket joints that would permit up and down movement between the two, but not sideways movement. Teeth were developed not on but from the jaws, for they were not dental structures in the modern sense but rather spiky outgrowths of the underlying bone. Where pectoral or 'breast' fins might be expected there was a pair of great spikes the true purpose of which is unknown. They may have helped in steering, or have controlled to some extent the rolling and pitching associated with the hind-end propulsion, or they may have been helpful as anchors to these bottom-cruising forms. A pair of hind fins was developed. Two forms are especially to be mentioned.

Firstly, the comparatively small *Coccosteus* which was about two feet in length and which is known from the Scottish Middle Old Red Sandstone. Its bone covering was well developed and was formed by nearly forty plates whose ornamentation shows, or suggests, that they were external and not covered. It also had only the up and down movement between the head case and the chest bones. It had, however, pectoral fins as well as pelvic; almost complete specimens of it show that it had developed arches for the protection of the notochord and thus had the elements of a backbone.

If the extraction and study of these primitive fishes appear remote from modern life, it may be well to point out that much of our knowledge of the second Arthodire we must specially mention is due to business men — American business men at that — who subscribed in order that a mechanical excavator should dig from the very centre of an Ohio city, Cleveland, the remains of several specimens.

Whereas the Scottish *Coccosteus* was but two feet long, the Ameri-

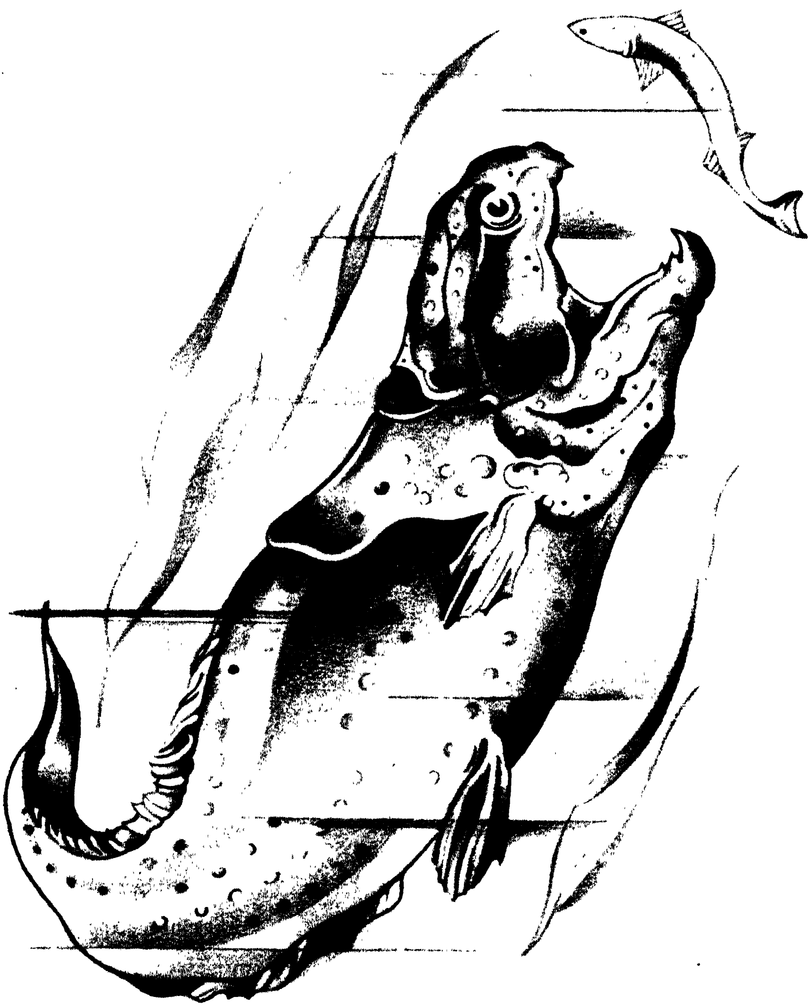


Fig. 35 DINICHTHYS
A primitive fish that grew to enormous size, the skull being sometimes three feet long

can *Dinichthys* ('terrible or huge' fish) was over twenty feet long. This great animal was perhaps one of the fiercest of Devonian carnivores. Its bony jaw elements, the so-called teeth, were capable of biting most of its armoured competitors in half. Of course, there are problems about it. It is said that it bit not by raising its lower jaw as most animals and men do, but by raising and then suddenly lowering its great upper jaw. Its plates, too, appear from their construction to have been covered during life by the skin.

So here (fig. 35) we see not merely a swimming 'tank', a defensive mechanism, but one of the first great vertebrate predators. *Dinichthys* was not the greatest for there was another American form, *Titanichthys*, that grew to nearly thirty feet long. Mighty as they were, they did not long survive the Devonian days.

The last group of the Placoderms we need mention are the Acanthodii which are higher than the lamprey type of fish but less efficient or developed than the later true fishes, though they are probably the oldest known fishes with true jaws. Superficially many of them were like the sharks, but the structure of their scales was quite different, and the protection of their gill region was not on a shark-like plan.

They had the fins characteristic of the sharks but each fin had at its forward end a well-developed spine, and some forms developed series of additional intermediate fins.

Their brain structure has been carefully studied and it seems certain that their visual sense was far more highly developed than their power of smell. They saw their prey before they could smell it and this condition is quite the reverse of that in sharks.

They were small, bottom-living, free-swimming fishes that lived on plankton, and they survived by many years the close of the Devonian, for their remains have been found in Permian deposits.

As a group, heterogeneous though it be, the Placoderms raise many interesting questions. They are well and defensively armoured but was this armour a chemico-pathological deposit that, as evolution went on, became less of a handicap, or were many of them bottom-dwellers through sheer necessity?

In dealing with the higher invertebrates we mentioned the great

Eurypterids, some of which were several feet long, and it may be that this armour was a defensive response to the real danger that threatened the earlier fishes from that source. The motility and power of Dinichthid forms would be an answer, in one case, to this challenge, and in this particular instance, as we saw, the armour was already less well developed and covered by skin. It is a fascinating problem and, as Sir Roger de Coverley would have agreed, 'much might be said on both sides'.

The Placoderms are additionally important, for modern students would seem to imply that from them were derived, somewhere, somehow, the great classes that have grown into the true fishes of more recent days, though none of them can be pointed out as a direct ancestor. Since the higher forms of fishes came into the geological picture in the Devonian it can be presumed that they descended from some Silurian form of Placoderm.

At any rate, the Middle Devonian saw the establishment of what modern specialists regard as the main lines of fish evolution, for we can from that time onwards see the great divisions: the Chondrichthyes, or cartilaginous fishes, and the Osteichthyes or bony fishes.

The cartilaginous group contains the sharks and their allies which have no bones in their skeletal make-up. It is true that as one traces the history of the modern sharks backwards there are breaks in the continuity, but nearly every period after the middle of the Devonian has its shark-like representative. One that is regarded as the best-known primitive shark is *Cladoselache*, which is shown, in fig. 35, being pursued by *Dinichthys*. Both fishes are, of course, known from the Upper Devonian of Ohio, and impressions of the skin of the primitive shark are not uncommon. The fish was more or less cylindrical in shape and it is interesting because the upper jaw does not overhang the lower as it does in modern sharks. Its paired fins are of interest also for they are balancing devices supported by cartilage rods, but, unlike the modern shark's fins, they are broad at the base. Sometimes the dorsal fins had spines.

An important point about the habitat is that the Placoderms would appear to have been slowly becoming marine and here in *Cladoselache*, as in nearly all later sharks, we have a marine form.

Although nearly all these later sharks were marine, some of the forms were occasionally tempted to return to the ancestral fresh-water habitat. A well-known example of such a kind is a much later form, of Carboniferous to Triassic age, known as *Pleuracanthus* (fig. 33). This was in many ways a remarkable form, for its fin arrangements are striking, especially the large dorsal fin running the length of the body. Behind the head is a great spine, nearly a foot long in some forms, whose purpose is quite unknown. The arrangement of fins and the nature of the teeth are markedly different from those of *Cladoselache* and the modern sharks.

The cartilaginous nature of the shark's skeleton, contrasted with the bony nature of the Placoderm ancestral stock, is to be regarded as a sign of skeletal degeneration.

The sharks are not, however, a group of fundamental importance like the fishes derived from the other great group of the Osteichthyes. From the nature of their scales the latter were often loosely called Ganoids ('bright-appearance').

One of the greatest branches of the group are known as the Teleosts ('complete-bone') which include the great majority of living fishes, but there are two branches, apart from these, that are of great importance in the history of life.

The first of them is the Dipnoi (or lung-fishes) which have a long fossil history. *Dipterus*, which lived in the fresh waters of the Old Red Sandstone times, is shown in figure 34. It was about fourteen inches long.

We have already seen that even among the primitive Antiarchi there were evidences of lung structure. It is easy to understand the function and importance of these organs, for these fishes lived in places that were liable to seasonal drought, and the modified air-bladder was a useful addition to the gills to get oxygen in times of stress. For this reason these particular fish are called Dipnoi which means 'double-breathers'.

They were not always successful, for they were occasionally surprised by sandstorms or cheated by too prolonged a drought, but they survived as a class and today their habits can be studied through *Epiceratodus* (fig. 36) which lives in the rivers of Queens-

land, Australia, or *Protopterus* from Africa, or *Lepidosiren* from South America.

The Dipnoi are not unique in the development and use of a lung or air-bladder; it was often well developed, and even had bony support, in the remaining great group of the bony fishes, the Crossopterygii ('fringe-finned' fishes).

The first members of this group appeared while the heavily armoured Placoderms were still much in evidence. They are thus an ancient group and were widespread throughout the world in the Devonian and Carboniferous but they disappeared soon after this, though not before they had made their mark in evolutionary history by producing some form that was almost certainly the ancestor of the Amphibia and thus of the first four-footed animal (or Tetrapod).

The transition is dependent not only on the early development of a lung-like organ that could be modified for use in a shore-living form, but also on the nature of the fins being suitable for adaptation to organs of progression.

There is evidence that lungs of some sort were in use in many fishes as early as the Devonian, but in the fringe-finned fishes the fin lobes had an apparently well-developed fin skeleton with strong muscles that suggest evolutionary possibilities. These fins were no doubt partly used in some forms for crawling on the muddy bottom, and from this habit the walking limb was inaugurated.

For many years there was much discussion as to whether the Dipnoans or the Crossopterygii were the ancestors of the land vertebrates and the discussion was confused by errors in classification and in problems of identification between the skull bones of fish and those of amphibia. This was especially so with regard to the bones surrounding the opening of the pineal or third 'eye' of the fishes and the Amphibia.

Of the various possible forms of Devonian fishes that might be considered for the ancestral role, the Pleuracanthid sharks came a little too late. The teeth of the Dipnoi were not of a character that could possibly be modified into the marginal cones typical of amphibians, so that by this elimination there remain only the Crossopterygians.

Of the last the best-known examples are *Osteolepis* from the Lower Old Red Sandstone of Scotland and *Eusthenopteron* from Escaumenac near Quebec.

These have limbs which could be transformed into the amphibian limb-type. They had teeth of the requisite nature and there is evidence that *Osteolepis* was accustomed to swallowing air like an amphibian. The primitive amphibian shoulder girdle is closely similar to that of *Osteolepis* too.

Osteolepis was a little fish about nine inches long, with well-ossified skull bones, and with rhomboidal scales on the body. There were a series of body fins and a prominent tail. Actually the fin structure of *Osteolepis* is unknown but that of the allied *Eusthenopteron* and others makes its form fairly obvious.

There are still problems but, none the less, considerations of the possibility of lung development, of limb structure, of the relationship of the elements of the skull, of the structure of the brain and of the habitat (fresh water) all lead to the conclusion that one of the advanced Crossopterygian forms of Middle or Upper Devonian age surmounted one more barrier on the evolutionary way.

Fig. 36 EPICERATODUS
The modern Australian lung-fish

It is perhaps significant that the thus important Crossopterygii, having delivered this momentous evolutionary offspring, gradually faded out of the scene. It is true, they did not completely disappear — they left an aberrant offshoot in the Coelacanth ('hollow-spine') fishes. They too were always supposed to have died out some sixty million years ago, but, alas for the omniscience of science, a perfect Coelacanth was pulled out of the sea by a fisherman off East London, in South Africa, in 1938. Unfortunately, its nature was not at first recognized, so that although the fish was eventually stuffed no anatomical study of it was made. Point is thus lent to the old adage that 'there are more fish in the sea than ever came out of it', but the purpose of this chapter has been in part to show that at one time, long ago, at least one fish came out to remain alive and to conquer a new element for the first time in the history of the vertebrates.

CHAPTER X

THE AMPHIBIANS EMERGE

WHEN we consider the emergence of the Amphibia, their origin from a fish with a closely roofed skull in the Upper Devonian, we must forget to a large extent what we think of the living amphibians, the frogs and toads, the newts and the legless coecilians. These are true Amphibia illustrating the characteristics of the class, but except to their ardent admirers they are not an impressive group, and it may be difficult to visualize them as constituting an important segment in the chain of vertebrate evolution. The modern forms are comparatively small, unattractive to look at, and still invested with something of the medieval repulsion referred to by Shakespeare when he wrote of 'the toad ugly and venomous'.

The Amphibia of the past were perhaps equally ugly, certainly they were ungainly, but they were not venomous, and many of them were of impressive size, even judged by our modern standards. They were, during the great Carboniferous period at any rate, the highest forms of life for some fifty or sixty million years.

When we say they were evolved from some kind of fish, what changes do we imply took place in the constitution and habits of the form involved?

The transitional stages between an Osteolepid Crossopterygian fish and the early plated-skull amphibian can be visualized with some clarity, thanks to a remarkable series of discoveries made in the Upper Devonian rocks of eastern Canada and of Greenland. In these places there have been found remains of nearly intermediate forms. Because these forms stand between the fish (Greek: *Ichthus*) and the primitive Amphibia with plated skulls (*Stegocephalia*, 'plated heads') they are known as Ichthyo-stegalia.

It is perhaps of peculiar significance that so many skulls, some of them amazingly complete, have been found of the early Amphibia. So far the amount of Ichthyostegalian material available is very small and is now largely preserved, and worked on by students, in

Scandinavia. The vertebrae of the Ichthyostegalia are so far unknown, and this is a point that we shall see is of importance. Related to them in some ways is a little form, *Diplovertebron*, from the Carboniferous of Bohemia, that shares some amphibian and reptilian characters.

In dealing with Amphibia there are two stages in the life history to be borne in mind: the swimming stage of the young, as befits a group with so long and so close a fishy ancestry; and the adult terrestrial form, although the adult female must return to the water to lay the eggs. Associated with these stages may be profound differences in appearance as, for example, between the tadpole and the frog.

Compared with the box-like back of the skull and the shoulder region of fishes, the amphibian skull is relatively free and is connected to the first neck vertebra by means of the two condyles or knobs near the middle of the back of the skull. All higher vertebrates, including man, have a condyle articulation with the first vertebra (atlas) of the neck. In the Amphibia and in man there is a double condyle; in nearly all reptiles and birds it is a single ball-like process.

The number of bones in the skull is reduced in the Amphibia, and the fish-like gills, retained even in some fossilized specimens of the young amphibians, are also lost in the adult. There are also changes in the bones adjoining the gill region.

A very important difference is in the region connecting the jaws and the ear, for amphibians have the upper jaw firmly attached to the skull, and the bone (hyomandibular) which is used to support the jaw in most of the fishes, now becomes partly free and adapted to a very different function. Its inner end is attached to that part of the skull associated with hearing and its outer end rests against the ear-drum (tympanum). Thus there is brought into being for the first time the highly important middle ear.

Apart from the skull, the skeleton must obviously be adapted for the new environment of the adult. For no longer can the buoyancy of water be expected to assist in locomotion, and the backbone, the limb-bones and their connections, must become prepared for the

Fig. 37 ERYOPS
An American Permian amphibian, about eight feet long

different stresses and strains associated with four-footed progress on the land. Thus, the bracing apparatus of the shoulder region (the pectoral girdle of amphibians and all higher classes) is strengthened by the introduction of a breast bone or interclavicle that helps to brace the two sides together. In some of the earliest Amphibia the shoulder girdle still has a special fish-like connection with the back of the skull but this is lost in most of the other, and especially the later, forms.

The girdle associated with the hind limbs (the pelvic girdle) is braced by an arrangement of the backbone, whereby at least one of the vertebrae has lateral processes which become fused to the pelvic bones. This is the beginning of a characteristic process known as the sacrum.

The vertebrae themselves show a number of conditions with bone more or less replacing the notochord. These various conditions

are used now as a basis of classification (see figs. 29, 30) but in this system we have not the advantage of knowing the primitive Ichthyostegalian condition.

The adult Amphibia have in nearly all cases a pair of front limbs and a pair of hind limbs, but there are certain degenerate legless forms (*Coecilia*, etc.). Most of the limbs are five-toed, although it will be seen that very many of the fossil forms have only four in the 'hand'. These limbs are without doubt derived from the paired fins of fishes but the actual stages in this process are as yet unknown, although Dr. Robert Broom and others have made interesting suggestions.

The Class Amphibia is divided generally into eight groups or Orders. Of these, as we have said, the tailed newts, the tailless frogs and toads, and the legless, worm-like and practically blind Coecilians are the modern, degenerate, or at least comparatively uninteresting, survivors of the large, primitive and widespread types we now must briefly describe.

The most important of the early Amphibia are those with the name we have already mentioned — the Stegocephali — which had roofed skulls with bones spread even over the places where the jaw muscles were attached.

They flourished during the periods known as the Carboniferous (when most of the world's coalfields were laid down), the Permian, and especially in the Trias (see Calendar of Life) and they must have been numerous and widespread, for their remains have been found in Carboniferous rocks of Great Britain and America and especially in the Permian and Triassic deposits of Germany, the U.S.S.R., India, Africa and Australia.

Despite this geographical range and the length of time involved, the characters of these dominant forms were essentially similar.

They had large, flattened, sub-triangular skulls with large openings for the eyes and the pineal. The bones that covered this head were sculptured, or ornamented, and bear the traces of the slime canals upon them (fig. 38). The teeth were large, often of complex structure, and ranged in great rows along the margins of the jaws and sometimes on the palate as well. The neck was short.

This prominent head with its large mouth must have made the animal in life look very much like a crocodile and the bite must have been tremendous. In many of these forms the body was very large, sometimes being as much as ten feet from the snout to the end of the tail.

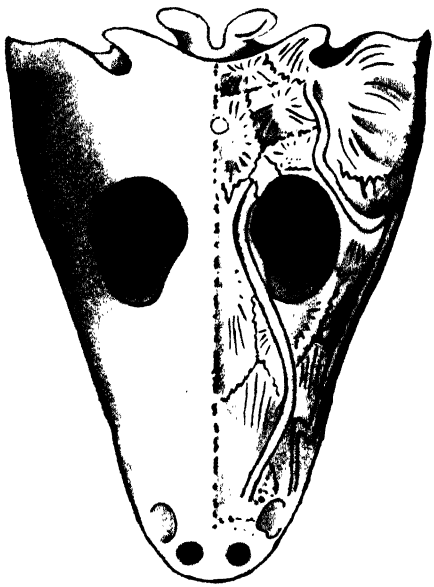


Fig. 38 SKULL OF MASTODONSAURUS
A typical Triassic amphibian from Germany. The skull is about eighteen inches long

This body was not only large but cumbrous, so that in the terrestrial forms the awkward limbs sprawled under its weight as they ambled over the marshlands. The bones of the upper part of the limbs (humerus and femur) were generally directed horizontally, jutting out from the body, and with the lower parts of the limbs at right angles to them. This sprawling gait is characteristic of the crocodiles too, except that when crocodiles are hurried they rise and walk or run on the straightened limbs.

The amphibian feet were originally five-toed, but, while most retained this number for their hind feet, many if not most of them had only four toes in the fore feet.

The largest group of Amphibia of this kind has become well known and its members are classed as Labyrinthodontia or 'Labyrinth-toothed'. This name is given to them because they have hollow, cone-like teeth whose wall is very elaborately folded (fig. 39).

The typical European member of this family is the Triassic *Mastodonsaurus*, a genus with several species, and in the largest of them, *Mastodonsaurus giganteus*, the skull was four feet long. Similar genera are *Capitosaurus* and *Cyclotosaurus*, closely related

forms, in which are found skulls varying from six inches to over three feet in length. It is estimated that the largest of these latter forms, which comes from the Trias of New South Wales, was nearly nine feet in total length. Its skull has a great battery of sharp teeth and it must have been a formidable foe of the freshwater fishes or perhaps anything else that came its way. These were all aquatic and some forms found in Spitsbergen were apparently marine, a remarkable thing for amphibians.

Remarkably good series of the European and Russian forms have been preserved. The remains of young ones are also known with traces of the gill arches.

It is clear from the incomplete circle of the rib girdle that many, if not most, of these forms would gulp air like a frog. Indeed, it is necessary to remind ourselves that this is so, for many lively reconstructions suggest a more highly organized life. A land-living form, *Eryops*, a favourite with the illustrators, is from the Permian rocks of Texas, in the United States. Many bones of *Eryops* have been found and, as they can be separated from their particular rock matrix without much difficulty, several nearly complete skeletons have been mounted with the bones in life-like arrangement. *Eryops* does not belong to the world's gallery of attractive animals, and we can visualize this scaleless monster, eight or nine feet long, sprawling in the shade by the side of the mud pools, but it was the summit of labyrinthodont evolution (fig. 37). For all its ungainliness it was a progressive terrestrial type with, for a time, a seeming hold upon the land. It was not to be, for the hold on land life was slipping and the later Triassic labyrinthodonts found, as many others in their time have also found, that they could not make the grade: these returned to the water, the ancestral habitat.

All the Amphibia were not like *Mastodonsaurus* or *Eryops*. Others, known as the Microsauria ('little lizards'), were, in fact, Stegocephalia that looked like little lizards. They differ in many ways from their larger relations, not only in having simple teeth and long lizard-like ribs, but they have a different kind of vertebrae, the bones of which resemble constricted cylinders or husks, hence the name often applied to them of 'husk vertebrae' or Lepospondyli.

The remains of these little animals have been the subject of some remarkably fine research work of recent years, although it is long since they were first discovered. Indeed their first discovery revealed the evidence of a tragedy of long ago, for the remains were found inside tree stumps of Carboniferous age where the amphibians had apparently been trapped. These specimens were found in Nova Scotia. A very fine series of remains was also found in the Coal Measures of Bohemia.

Not all of them were so small, for a remarkable American form, *Diplocaulus*, is known, with an extraordinary, boomerang-shaped skull. This was a flat-bodied water-living animal. Many of these Lepospondyls were apparently gill-breathers throughout their life.

Remains of related forms, which had apparently secondarily lost their legs and become like snakes in shape, are also known and their significance will be mentioned later.

The last little group we need mention contains the so-called Branchiosaurs or 'gill-lizards', also known as Phyllospondyli (leaf-vertebrae) on account of the structure of their vertebrae. They too have been exhaustively studied in the last decade and they obtained their name because the young individuals show so well the structure of the gill arches. They were small salamander-like animals, several inches long, including the tail. Only the skeletons as a rule are preserved, but in one instance the impression of a comparatively long tail was found. It now appears clear that they are not a separate group but just the young of Labyrinthodonts.

It is significant that of similar age to the great developmental period of the Amphibia there are many footprints which have been found in America, England and Europe (fig. 40). These have, in most cases, no connection with any skeletal remains, and so it is impossible to determine their exact nature, but the presumption is strong, especially as many of the prints have apparently four-toed 'hands' and five-toed feet, that they are probably amphibian in origin.

Now, this brief picture of the amphibian scene is, of its very nature, unsatisfactory. The classification of Amphibia largely depends upon structures which are only adequately comprehended in

the presence of specimens. The rise and fall of amphibian forms is not easy to delineate as several 'strings' of them were in competition, in growth or decay, side by side. There is, too, the long gap in their history in the later, Mesozoic, geological times that seems to dissociate these early forms from the admittedly feeble or degenerate forms that we can see alive today. To counter this, a very short account of the evolutionary direction of the Amphibia will be given in conclusion.

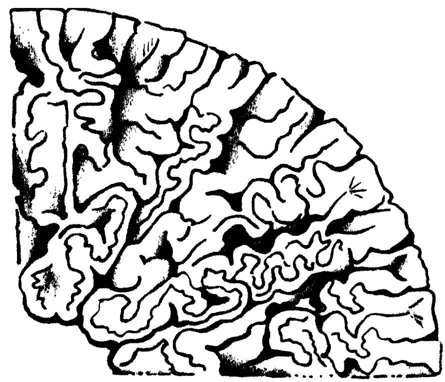


Fig. 39 A LABYRINTHODONT TOOTH WITH ITS INVOLVED STRUCTURE

Before we come to this, there is an important, but intentional, geological omission that must be rectified. It concerns our old friends, the invertebrates, whom we left, somewhat contemptuously, as we paused to consider the evolution of the vertebrates from them, and since then, we have briefly glanced at the rise of the fishes and the Amphibia.

We left the invertebrate world to the doubtful mercies of the Arachnids in the Upper Silurian, yet, in the last few pages, we have been talking about the Devonian, the Carboniferous, the Permian and even the Trias. What was happening during that great interval to the collateral forms of invertebrate life and on the lands that were the background of the newly terrestrial vertebrates? Assuredly they were not quiescent, and assuredly the invertebrates did not abandon the struggle for existence when they saw higher forms in the sea or new sprawlers on the land. If we are to assess with truth the progress of the vertebrates it must be with an eye upon the invertebrates and the land plants as well.

When we spoke of the lands it was of their barrenness and the fact that there were probably algae and a few lichen-like growths upon the rocks near the shores. In the interval, while we have been

following the rise of the fishes and the amphibians, much has happened in the seas and on these land surfaces.

The Silurian period was, climatically, generally warm. As we have seen, the invertebrates were well developed and widespread both in the seas and in the shallow in-shore waters.

The Devonian period was warm at its inception but probably only moderately so towards its close and it gave rise to some very important events. We saw earlier that during it the Nautiloid forms of cephalopod Mollusca were common, but in it also certain forms of Cephalopods developed the wavy septal lines that indicate the characteristically sutured Ammonites, which were to become so important in the later Mesozoic age.

We have also in the Devonian to consider two types of geological deposit which go together towards its formation but which cannot obviously co-exist. The one series consists of the true Devonian type of deposit that was laid down in the water; the other is a terrestrial deposit, formed during seasonal alternations by the accumulation of materials on the land, and is of a red, sandy nature, known as the Old Red Sandstone. We have already mentioned some of its characteristic fishes, long known to us by the classic researches of Hugh Miller.

But it is also in the rocks of Devonian age that the first real record of land plants is found. This is an evolutionary change of immense importance, for all the earlier plants, so far as they are recorded by fossils, were of the algal or lichen type. Here, however, for the first time, we see the rise of the vascular plants, with fluids in circulation through their fibres, the very basis of the kinds of plants that were to clothe the earth as succeeding ages passed. This is also a remarkable coincidence, that the earth should be clothing itself with the very mantle upon which all animal life depends at the very time when, out of the shallow waters, the progressive forms of that animal life were struggling for a foothold on the land.

The developing stages of this primitive flora are lost but simple forms have been found in a rock known as the Rhynie Chert from the north-east of Scotland. The remains of the plants there show leaves and stems and appear to have been part of a bog-land series.

By the closing stages of the Devonian period plants had made great progress for there were ferns, kinds of horse-tails, and the forerunners of the conifers. Indeed, the first forests would seem to have been formed.

The Carboniferous period, which succeeded the Devonian, was one of luxuriance, for the climate over most of the period was warm, and the plants had flourished. The ferns were huge, the fern trees tall, and the great *Lepidodendron* ('scale tree') trees were four or five feet in diameter and nearly one hundred feet high. There were forests and great swamps, but none of the trees or bushes was flowering; there were no deciduous trees and all the vegetation was of a sombre hue. Nor was this relieved by the passage of bees or bright butterflies, though insects were now in flight, but their highest forms were the dragon-flies, culminating in the giant *Meganeura* with a wing spread of over two feet.

It was, then, in this world that the battle for terrestrial life was fought by plants, by invertebrates, and by the vertebrates as well. And all of them won.

The sounds were the wind in the fronds, the whirr of dragon-fly wings and the reverberating croak of the giant amphibians. The crash of falling trees and the splash of the swamp-waters drew attention to a strange process that was also going on, the accumulation of vast deposits of trees, undergrowth, fronds and swampy materials, that were eventually to consolidate and to be compressed to the coalfields of the world, the very foundation of men's economic power.

On the hills the sparse conifers were growing much as they do today; in the swamp-lands there were the ancestors of modern plants; in the undergrowth were the advance guard of the insect hordes, the millipedes and the cockroaches.

If the dragon-flies attained their maximum in the Carboniferous, so nearly did the amphibians, for their survivors at its close were numerous and widely spread, but the seeds of degeneracy were already cast amongst them and some of them had not long to survive. They were, of course, still largely aquatic, leading crocodilian kinds of lives in the swamps.

The close of the coal-forming age saw glacial periods in some parts of the world but, generally, the next period, the Permian, was moderate in temperature and arid at its close.

The sombre vegetation still dominated the land and true conifers were common. Indeed, so widespread were the plant forms, and

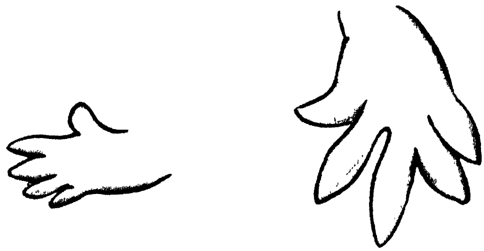


Fig. 40 FOOTPRINTS OF LABYRINTHODONT AMPHIBIA

so similar, that the lands must have been much more extensive and closely connected than they are now. Again the larger amphibians, the ones with rhachitomous vertebrae (fig. 30), made valiant struggles to be landsmen, and it was at this time that the land-living *Eryops* (fig. 37) flourished. They were large, with strong limbs, and they were as terrestrial as they could be, apart from the fact that amphibians must return to the water to breed.

But a stranger was already in their midst; in fact, by now the stranger had multiplied, and it and its fellows had one advantage over them that it has never lost; it did not have to return to the water to breed, for it was a reptile.

The evolutionary lines of the amphibia are not clear. The Labyrinthodonts, faced with increasing competition, returned in the Trias to the waters and to obscurity but they may have given rise to the form that passed the torch of amphibiousness down to the modern frogs and toads, though the geological records of these are not long.

The little Lepospondyls or microsaurs are thought to have given rise similarly to the modern salamanders (fig. 7) and they may also have been the forefathers of the legless coecilians.

Somewhere in the amphibian chain was a link, probably close to *Diplovertebron*, that gave rise to a reptile, probably in the Carboniferous days, for in the Permian true reptiles were well established. The days of amphibian splendour were soon over, but they could safely dwindle in the Trias towards partial extinction, for they had done their task. The flame of progress had been handed on, even though it was not to an amphibian.

CHAPTER XI

REPTILES CONQUER THE LAND

THE reader who has glanced at the chapter headings of this book may be astonished to find that no fewer than four of them are devoted to reptiles in one habitat or another. This is certainly a larger space than is devoted to any other group and, when one considers the animal world of today, it seems an unwarranted amount of advertisement for an unattractive group. Today, we have lizards, snakes, turtles and tortoises, and the crocodiles, and none of these is likely to arouse interest or affection when compared to the great fauna of attractive, useful and domesticable mammals, or the gay and friendly birds.

But just as the last degenerate member of a noble house may be unattractive and uninspiring, so the reptiles of today are but the veriest shadow of a mighty dynasty that held sway from the Carboniferous to the end of the Cretaceous. For one hundred and sixty million years they were the highest forms of life on land, in the sea and in the air. After a brief history of less than a million years man need not decry them because their hold on life eventually relaxed. No other group has so far equalled their dominance in time or diversity. None may ever do so. Bearing these facts in mind a glance at the reptiles of the past is not unwarranted, even if it is only in four chapters and not in the four volumes that it deserves. In the circumstances, however, considering the complexity and diversity of the group, their anatomical peculiarities, and the physiological problems that their life arouses, it will be better to treat them, not as a few anatomical or osteological entities, but rather as the living members of a pageant in the story of Mesozoic life.

Yet, as in other family histories, it was not the spectacular forms that were ultimately the most successful or important. Interesting though these were, dominant for centuries in their respective fields, they yet left no descendants. The evolutionary destinies of the

reptiles were settled early in the day among the small, uninspiring and unadorned of their kind.

The relationship between the Stegocephalian amphibians and the earliest known reptiles is close. Indeed, in the earliest of all the reptiles so far known, of Middle Carboniferous age, the difference from some of the Amphibia would appear to be a matter of the number of the bones in a toe. Yet such apparently slight characters are not in fact trivial and the wide study that has been made of fossil forms has shown remarkably stable bony features.

The earliest reptiles are Stegocephalic too, in the literal sense, for they have completely roofed skulls, apart from the openings for the eyes and of the pineal foramen. This point is of some importance for the modern classification of the reptiles is based upon the number and position of the openings in the skull additional to those for the eyes (see fig. 51, for example). The reptilian backbone in nearly all cases is completely bony, and the number of fingers and toes, as well as the number of bones in the digits, is remarkably stable in many forms, although susceptible in others to alteration of both features by adaptations of various sorts.

Two of the most variable features, curiously enough, are the relative size of the skull and the length of the neck. Even in the same group of reptiles, one form may have a head relatively enormous compared with that of another member. In the neck almost any number of vertebrae is possible, in marked contrast to the standard one vertebra characteristic of most Amphibia and the seven cervicals typical of nearly all mammals, whether shrew or giraffe.

The fundamental group of reptiles is known as the Cotylosauria, or 'cup-lizards', in reference to their cup-shaped vertebral ring, and it seems fairly certain that this type of vertebra could only be derived from the Amphibia known as Embolomeri, that is, the group that contains the Ichthyostegalia and *Diplovertebron*.

The Cotylosaurs probably evolved during the early Carboniferous and remains of them are known from Carboniferous deposits in North America. They are abundant, however, in the Permo-Trias of South Africa, in the Permian of Russia, and an interesting form is found in the Middle Trias of Scotland. Some of the Cotylosaurs

Fig. 41 DIMETRODON

A remarkable Permian reptile about nine feet long

were small but others were large as judged even by mammals of the present day.

One of these large reptiles is amongst the best known of them all: it is called *Pareiasaurus* ('helmet-cheek reptile') on account of the bony roofing of its face and top of the head. The large, triangular, flattened skull is a remarkable piece of solid bone formation, but there are large openings for the nostrils, eyes and the pineal organ of sensibility to light. It had a long, heavy, bony vertebral column, with massive limbs to support it. The limbs are of the sprawling type, with the 'elbows' and 'knees' well stuck out from the side of the body, but the angle between the upper and lower limb-bones is greater than a right angle. There are five digits in each foot, and the feet are said to have been adapted for digging.

The living Pareiasaur was an impressive creature of heavy build (fig. 42) and the massive body would need the support of the heavy limbs. It would be interesting to know the complete, if primitive, musculature that maintained the creature in its slow and ungainly progress. The adult was from eight to ten feet long, and its skin would appear to have had warty excrescences upon it. The bony head itself had sculptured bones, at least in some forms. The teeth extend not only along the jaws but on to the palate as well, and the animal, which is thought to have been a herbivore, must have been a kind of perambulating vegetation crusher.

Remains of *Pareiasaurus* are well known from the Permian of both South Africa and Russia, and a very great deal of work has been done upon them by Russian palaeontologists.

The systematic position of this bony family is reminiscent of a Hindu concept of the earth's support, in which the earth is thought to be borne by an elephant standing upon a tortoise. The tortoise, aptly enough another anapsid, bears then the complete burden and it is roughly true that the whole of the higher reptilian, avian and mammalian branches of life rest upon the fundamental Cotylosaurs.

Not all the Cotylosaurs were so large or herbivorous in habit, for some of the American forms were from six inches to about four feet in length. These were sprawling creatures, not very unlike their amphibian ancestors in appearance and habits, but their teeth were

of the crushing type and some of them may have lived on shell-fish, though others were herbivorous. One of them, *Seymouria*, from the Permian of Texas, is still a debatable link, for some authorities class it as a primitive reptile, while others stoutly maintain it is an amphibian.

One of the later types of Cotylosaur, living in the Trias of South Africa after the last of the Pareiasaurs (for they did not survive the Permian), was the small *Procolophon*, representative of the stock of smaller members of the group. It had a deep triangularly shaped skull. The teeth were few in number and those towards the back of the mouth were adapted for chopping up vegetable food.

This small kind of Cotylosaur spread, for the remains of closely similar forms are found in Europe (including Scotland) and in North America as well as in South Africa. It is significant that some of them were developing spiny protuberances on the skull. Indeed,

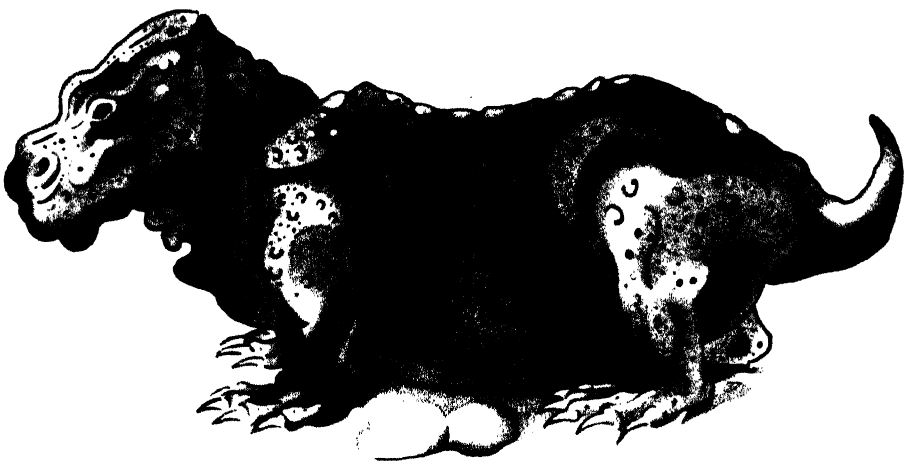


Fig. 42 PAREIASAURUS BAINI
A primitive S. African reptile, of Permian age, about nine feet long. Similar reptiles have been found in N. Russia and NE. Scotland

the little *Elginia*, from the Permian of north-east Scotland, has a skull that is adorned with a remarkable series of spikes.

This feature of spinescence, as we shall point out in many groups of reptiles and of mammals, is frequently the herald of extinction, and the physiological explanation of it is given in the last chapter. At any rate, it presaged the disappearance of this great basal group of reptiles, which passed away to leave room for more progressive evolutionary reptiles.

A group that was derived from the primitive stock, but flourished only in the late Carboniferous and the Permian, was composed of the extraordinary creatures known as Pelycosaurs. Their remains are especially well known from red beds of Permo-Carboniferous age in Texas. Some were large and some were small, but they were longish, sprawling, lizard-like creatures with long tails. They had deep skulls whose jaws had numerous sharp teeth adapted for a fish diet, although a few of them seem to have been herbivorous.

Their chief claim to popular fame is the peculiar lengthening o the spines of the backbone which stick up for two or three feet in some well-known forms. *Dimetrodon* ('two-sized teeth') is one of these (fig. 41). This animal grew to about eleven feet long and had a monstrous series of spines on its back which was covered by a web of skin during life. These animals are often, on account of this, known as the fin-back reptiles. The precise function of this web, or sail, is not known but it has served for the text of many strange tales. For example, since *Dimetrodon* has different-sized, sharp, biting teeth in its jaws, and since its bones have been found associated with fish remains, it has been pictured as swimming in the waters in pursuit of its prey, aided by some favourable breeze in its sail. This is an imaginative explanation. Others, more physiologically minded, have assured us that, as the temperature of reptiles is not under their own control but varies with that of the surroundings, so the blood supply to this great sail was a cooling mechanism; that it was, in fact, a primitive radiator.

Unfortunately for these theories there was another form living at the same time that was herbivorous. This is *Edaphosaurus*, also about eleven feet long, and it had not only the great vertebral

'masts' for the so-called sail, but it developed cross-pieces on them as well, yards in the sailing-ship sense. But the plant-eating *Edaphosaurus* had no need to go to sea, and its cooling mechanism would be little improved by 'yards'. Far from a help, the extra weight would be an encumbrance to a herbivore that might need all its speed to escape from its fellow Pelycosaurs who had a taste for flesh and were not over conscientious as to its source.

It looks very much as if this bony development was not an accessory structure of any value at all to the animal, but was just another example of growth become riotous, another prelude to extinction.

The Pelycosaurs, grotesque and problematical, were soon extinct, but the larger circle to which they belong is of great evolutionary interest, for from them developed a great series of diverse animals, known generally as Theromorphs or Therapsids, the 'beast-forms' or 'beast-opening skulled' animals. They are sometimes also called the Anomodontia ('irregular-toothed').

Many remains of them have been discovered and from such diverse sources as Europe (including Scotland and Russia), North America, India and Africa.

By far the most prolific source of our knowledge is that great series of beds developed in the Karroo of South Africa. This is in fact a vast graveyard of representatives of this highly important stage in reptilian development and, by the constant and inspired studies of a few men, a great deal of its evidence has been interpreted as a fascinating and convincing chapter of the history of life.

Some of these animals again were large; others were small. Some were herbivorous; others great carnivores. A few were secondarily adapted for living, or at least for securing their prey, in water. Most, however, were creatures of the land. They persisted throughout the highly formative times of the Permian and Trias and the aridity of these periods may well have provided an important stimulus, since it obviously set a premium on those who could travel easily and far for the food and drink they needed. This stimulus, this elementary search for the bare necessities of physical

life, emphasizes two characters of higher significance, mobility and mentality.

Perhaps the nearest of the Theromorphs to the Pelycosaurs were the Dinocephalia, or 'huge heads', large animals sometimes ten feet long, with large bodies but still with sprawling limbs like their ancestors. Some of them were flesh-eaters who preyed on the Pareiasaurs but many, as in all groups of large animals, lived upon plants. They were all Permian forms.

A very fine example of a Dinocephalian is *Titanophoneus* whose remains have recently been found in Russia. This was a carnivore twelve feet long and a reconstruction of it is shown in figure 44.

Nearly related forms of the same geological age were the Dromasauria ('running-lizards'), animals of slender build with more graceful limbs and a long tail. They are notable in having had small heads with large eyes. A well-known example is *Galechirus* ('weasel-hand'). Some of the Dromasauria were toothless.

Another group is the Dicynodontia, or 'double-dog toothed' animals, which had in many forms, though probably only in the males, great canine teeth, on the upper jaw, that developed into tusks at the side of the turtle-like beak. These peculiar animals were marsh-dwellers and were widely distributed throughout the world, and a smaller animal of this type, with smaller tusks, has been found in rocks at Elgin in Scotland. Other forms, of which quite good skulls are known, lacked the tusks. The beak is not the only turtle-like character in the skull, for the condyle that provides the joint between the head and the neck is shaped like a clover leaf, a condition that occurs in the tortoises and turtles.

One of the Dicynodonts, of which many skulls have been found, is an aberrant form, for although it had tusks, it had its nostrils near its eyes instead of at the tip of the snout. This suggests that it was water-living, for with such nostrils it could breathe comfortably and yet have its mouth open, to a small extent, under the water. Its eyes, too, were strengthened by sclerotic plates, and these, though they occur in many reptiles, were especially well developed, as we shall see later, in those that lived in water. This reptile is known as *Lystrosaurus*.

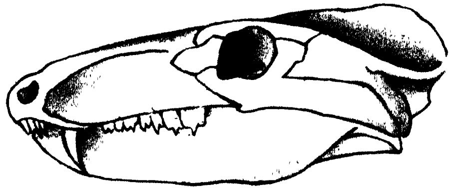


Fig. 43 SKULL OF A MAMMAL-LIKE REPTILE, CYNOGNATHUS, FROM THE TRIAS OF SOUTH AFRICA
Length of skull fifteen inches

The last group of the Theromorphs provides by far the most intriguing and the most significant members of the order. As we have said, the word Theromorph is coined from the Greek words meaning 'beast-shaped', but the beast in mind is the mammal. This connotation is not peculiar, for even today many writers use the word animal in a similar restrictive sense. This point is made because the name of this last group also contains the word beast — the 'beast-toothed' — or Theriodont reptiles. They are called this because of their dentition.

All the reptiles of which we have been writing, and which were toothed, had the sharp conical teeth of the crocodiles, or specialized teeth for grinding shells or chopping vegetation, but all the teeth in the jaws were, in the main, similar in structure, although they might be different in their state of wear or age. The Theriodonts have, however, a new kind of arrangement, for they have teeth of several different characters, obviously for different purposes. This dental equipment is so like that of a dog that these animals are also known as Cynodonts, that is, 'dog-toothed' reptiles. A very typical example is that of the early Triassic *Cynognathus* ('dog-jaw') (fig. 43). The skull itself, although comparatively large, is dog-shaped, but in the jaws, at the front of the mouth, is a series of biting teeth or incisors: at the side, behind the incisors, is the prominent canine tooth (the eye-tooth of human beings); and behind that, and towards the back of the jaw, is a series of molar teeth. This is a mammalian arrangement, and indeed in some of these reptiles the affinities with the mammals are so strong that the reptilian features

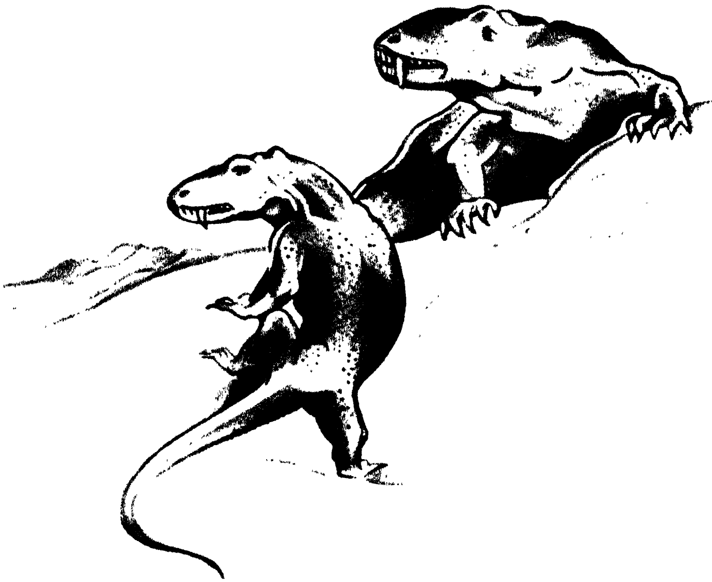


Fig. 44 RECONSTRUCTIONS OF YOUNG AND ADULT REPTILES, TITANOPHONEUS POTENS, FROM THE SOVIET UNION
The adult was about twelve feet long

are only the hingeing, and the associated musculature, of the jaws. That is, as far as appearances go. Actually the Cynodont teeth were not replaced in the way that the mammalian teeth are. *Cynognathus* was a flesh-eater, but some of the others were vegetarians.

Another mammal-like feature is the occipital condyle, the process by which the skull moves upon the first vertebra of the neck. In mammals and in amphibia it is double and in nearly all reptiles it is single. Here, in these Cynodonts, it is double.

There are many other features in the arrangement of the shoulder and hip girdles, in the presence of an elbow, and in the structure of the feet, that point towards the mammal. So here again we see that quite early in the reptilian development their maximum evolutionary progress was made. Reptiles were to flourish for a hundred million years yet, in great and diverse groups; many were to survive even to the present day; but the major achievement of their history was amongst the small, comparatively unspecialized and early members.

It is not improbable that in the favourable surroundings of what is now South Africa the transition from reptile to mammal took place, but the progenitor was certainly not *Cynognathus*.

Within recent years much work has been done on a little reptile of a similar kind, known as *Tritylodon*. For some time it was actually considered to be a mammal. During the war years some fine material related to it was found and worked out in England and it has been proved to be a reptile, but one so specialized that it cannot be the ancestor to the mammals.

Why is it that, with all our knowledge and our material, we cannot pick out the transitional form, that the link is always a missing link? Let us consider the Karroo, that great graveyard of the youth of life. Dr. Robert Broom, a distinguished doctor of science and medicine, who has done most of the work on this subject, points out that the great Karroo deposits lie comparatively untouched. Man's collecting efforts merely scratch the surface, and most of its evidences of reptiles and mammals lie buried. Skeletons are occasionally washed out in the watercourses, but most of them rot and disappear in obscurity.

From that great deposit of two hundred thousand square miles, Dr. Broom estimates, or rather he knows, that twelve hundred different kinds of these reptiles have been discovered, but he estimates that within that colossal burial ground there may be eight hundred thousand million remains. Yes, 800,000,000,000!

The twelve hundred forms that we know are signposts to the one or two specimens that might be hailed as the links. We can with sincerity point the road along which life has travelled, but, alas, the history of most of the travellers is lost.

For our present purpose it must content us that probably in South Africa and probably from a kind of reptile near to the Cynodonts in its organization, sprang the first mammal, the great-great-grandfather of us all.

CHAPTER XII

THE DINOSAURS

We have just been dealing with the origin of the mammals which, we said, probably took place in the increasing aridity of the Triassic period, commonly known as the Trias. What was this time and what were the conditions, geographical and climatic, that then prevailed?

It is important to us in many ways, for if the mammals made their bow during its course, it was obviously the beginning of a new and highly important volume, rather than chapter, of the history of life. It is generally considered that this is so, for the Era, or group of periods, that it ushered in is called the Mesozoic Era, that of middle life. Life, we may say, has grown older and more experienced. It still has its diversions but these are likely to be more serious.

Geographically the world was very different in its distribution of land and sea from the present condition, and the map of these days was not arranged on anything like its present plan of great land masses running from north to south.

There were two great land masses, of fairly uniform depth from north to south, but they ran from east to west. The northern mass included most of what are now North America, the North Atlantic, Greenland, Iceland, Great Britain, Europe and a very large part of the Soviet Union. This mighty continent is called North Atlantis in its western half and Eurasia (or Palaearctis) in its eastern part.

The almost equally great southern continent included what are now South America, the South Atlantic, Africa, Madagascar, the Indian Ocean, India and Australia, and it is called Gondwanaland.

The two were separated by a long (from west to east) but narrow sea called Tethys, of which the Mediterranean is now perhaps the only remnant.

The climate was warm and equable to arid. The seas were

occupied by the fishes, grown old in their freedom, but the Ammonites were there in numbers too, each clothed in its complex shell. On the lands the conifers were well established and the palm-like

Fig. 45 MEGALOSAURUS
An English Jurassic dinosaur, about twenty feet long

cycads were widespread. In the undergrowth the little mammals pursued the exploration of the world they were to conquer. They had come, they were seeing, but they had still to conquer, and from time to time they had to scuttle away as a lord of creation, a reptile a few feet long, passed by.

All this was a long time, nearly one hundred and ninety million years, ago. And the age that the Trias ushered in, this Mesozoic, was to last for one hundred and twenty-five million years, a very handsome lease of Time's mansion.

The following periods, the Jurassic and the Cretaceous, were still played upon much the same grounds and under very much the same conditions. Cycads and conifers, great reptiles and little mammals on the lands; little fishes and great reptiles in the seas; primitive birds and great reptiles even in the air.

This was the age of reptiles. Not poor crawling things like snakes, or dull objects like turtles, but great creatures that might add pride to any ancestry.

It is true that at the beginning of the Trias, this greatness was

not observable, that the shadow of coming events had not darkened the world noticeably, but it was there.

There was living at that time, and again the scene is South Africa, a group of little reptiles of some interest. They were interesting even for themselves, for in their little skeletons there was much that was of anatomical significance, of evolutionary potentiality, that suggested a reaction to the forces, and experience, of life and its environment, and that boded well for their future. Like so many promising lads that have gone into the world, they made much less of it than might have been expected, but they left descendants that were of the race of kings.

This little group is called the Thecodonts, from the Greek words for 'teeth in a groove', for one of their characteristics was that in their jaws the teeth were in a row round the edge; none was on the palate. The skull was small and lightly constructed, with large openings for the eyes, and furthermore there were openings, through bone reduction, on top of the head and in the side of the head behind the eye and also an opening in front of the eye. These were paired openings, openings that cause these reptiles to be known as Diapsids (two-arches). But there was no foramen for the pineal. The skeleton was well developed and the tail was as long as the body. The hind legs were long and suggestive of some power, but in many of them the fore limbs were short and unsuited for locomotion. The hip girdle was adapted to meet the stresses and strains of a new hind-legged mode of progression and the long tail obviously served as a highly useful balancer.

This is a rough picture of a Triassic Thecodont. But the important thing about such a creature is not its size — it was nearly four feet long — or its gracefulness in contrast to the gross and lumbering forms we have seen lingering into the Trias from the Permian, but the fact that the reptiles had at last got their bodies off the ground!

This pose, accompanied by well-developed and agile limbs, may well be the beginning of great evolutionary progress. The Thecodonts themselves made no great mark in the world but they did give rise to the dinosaurs, the greatest land animals of all time; to

the crocodiles, of the seas and rivers; and to the pterodactyls, the flying reptiles.

The dinosaurs are popularly regarded as one great group of reptiles of diverse habits which first appeared in the Trias and persisted until the close of the Cretaceous. They were world-wide in distribution yet much about them is still obscure. It is, however, clear that they are separated into two parallel groups, though these had been derived from the Thecodonts we have mentioned above. Anatomically, one group is distinguished in having a purely reptilian arrangement of the hip-girdle bones and is thus called the Saurischia, 'reptile-hips', and the other has an arrangement that is typical of the condition in birds. The latter are, therefore, called Ornithischia or 'bird-hips'. Both groups are distinguished also by slightly different arrangements of the teeth in the jaws of their respective members. These differences will be pointed out when we describe the main sub-divisions. Scientific authors refer to them as the Saurischia and Ornithischia, but it is probable that they will always be called the Dinosaurs in ordinary literature, for they were first studied and named by the great English anatomist, Sir Richard Owen. In these early days their affinities were not clearly recognized, and Owen, in fact, referred some of the largest dinosaur bones to the crocodiles. At the time their size was regarded as striking and so Owen coined the word dinosaur from the Greek *deinos*, huge, and *sauros*, lizard or reptile. The actual meaning of the Greek word *sauros* is lizard, but it can generally be interpreted for our purpose as reptile.

Fig. 46 TOOTH OF MEGALOSAURUS (ACTUAL SIZE) SHOWING SAW-LIKE EDGE

A remarkable fact is that both dinosaur groups can be divided

into sub-divisions with bipedal and large quadrupedal forms. To try to describe them all, or even the small groups within the groups, would require a large book, so that all we can do here is to give an outline of some of the more interesting forms, of which illustrations are also given.

The Saurischia may be described in two sections: the first devoted to the bipedal carnivorous forms known as the Theropoda, 'beast-feet', and the second containing the great quadrupeds, the Sauropoda or 'reptile-feet'.

The Theropoda first appear, like the others, in the Trias, as small leaping animals only a few feet long. Their remains are known from Scotland, Germany and the United States. Somewhat larger forms occur in Germany and they have been called *Plateosaurus*. This was a primitive bipedal dinosaur, rather clumsily built. It had a small head on a barrel-shaped body and the tail, as befits a balancing organ, even a primitive one, was long. There is little doubt that this dinosaur was at least partly bipedal, for although the hind legs were clumsy and the feet were five-toed, the fore limbs were so constructed that they were not suited for walking and the clawed hands appear to be better adapted for grasping prey.

The teeth in the sides and front of the jaws were compressed from side to side and their front and back edges were serrated. They thus give confirmatory evidence that this was a predacious reptile, who lived upon swimming reptiles and fishes in the lakes and streams. *Plateosaurus* was a formidable creature for his time and his total length, some twenty feet, was large for the Triassic members of the group. (Fig. Tailpiece, Chapter I.)

The next dinosaur we must mention is not, in some ways, so completely known, yet historically it is far more important. for it is *Megalosaurus* (the 'large reptile'), the first dinosaur ever to be discovered. The classic example was found in 1824 near Oxford, and since then many fragments of it have been discovered in many places but it still remains imperfectly known. Our knowledge of it is still not the carefully collated study of well-developed or complete specimens, but rather a hotch-potch of tantalizing pieces.

Despite this, the nature of the animal is fairly clear. It was as

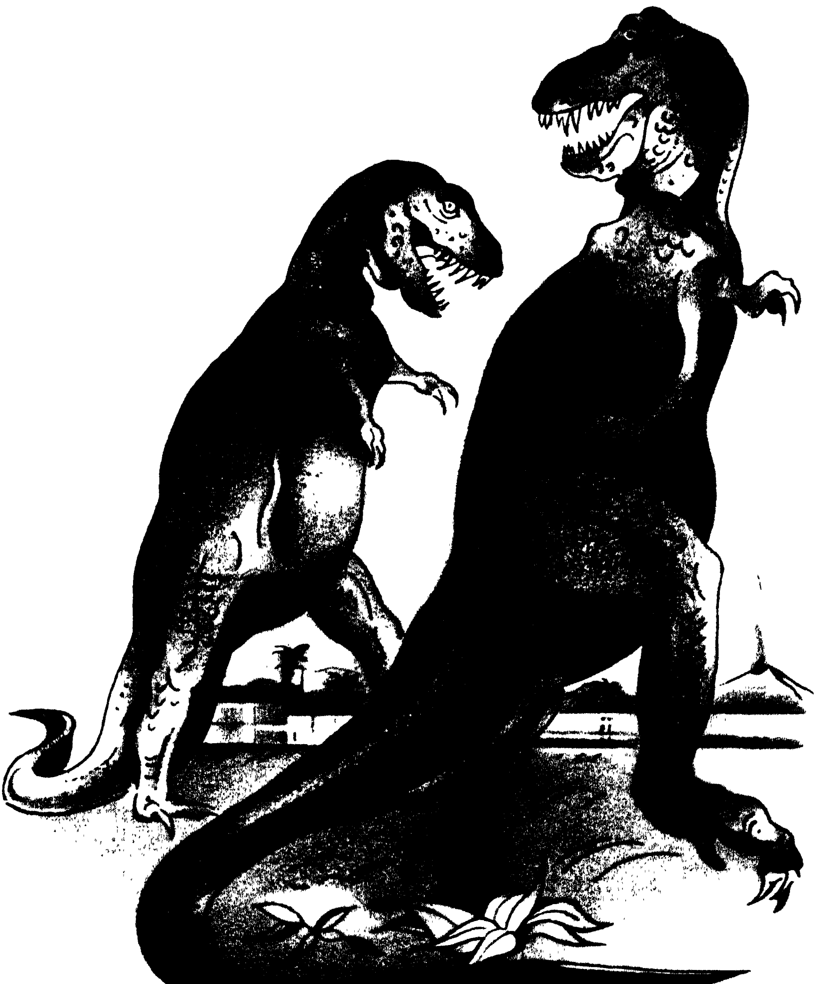


Fig. 47 TYRANNOSAURUS
A giant carnivorous dinosaur, nearly fifty feet long and twenty feet high

large as *Plateosaurus*, and it was certainly carnivorous, for we know that the skull was at least a foot long, and we have fragments of jaw with the compressed, serrated, recurved teeth protruding two or three inches above the jawbone (fig. 46).

The reconstructed picture of *Megalosaurus* (fig. 45) shows that in its maximum development it must have been twenty feet from the jaws to the end of the tail. The neck was stout, and the body long yet bulky. The tail was flattened a little from side to side and was heavy enough for its function as a balancing organ. The hind limbs were used for walking and the feet were three-toed and clearly digitigrade. That is, the dinosaur walked on its toes, rather than on the soles of its feet. This is an advanced state of affairs compared with the foot of *Plateosaurus* and is more suggestive of speed.

A similarly advanced condition is seen in the fore limbs, for they were smaller than those of the earlier German dinosaur, and they could not have been used for walking. Though the hand had still five digits, the outer two, that is, the fourth and fifth fingers, were reduced in size. Both hands and feet had strong claws.

Megalosaurus lived during the Jurassic period, in Europe and in Africa, and in those days there would be an abundance of both reptilian and mammalian life on which to exercise the strong jaws and the cruel teeth.

Some similar forms, represented by much more complete and satisfactory material, are known from America. One of these is closely similar to *Megalosaurus* but it had a horn on the nose and hence it is called the horned-reptile, *Ceratosaurus*. It seems to have gone in for adornments of this sort for there is reliable evidence that it had a series of bony plates along its back. It was more slenderly constructed than its English relation and both the hind and fore limbs show even better adaptation for the capture of prey. *Ceratosaurus* was of Upper Jurassic age.

This tendency towards 'Nature red in tooth and claw' reached its culmination in these predacious dinosaurs in the Cretaceous where ample remains of the monstrous *Tyrannosaurus* ('tyrant reptile') have been found. The original specimen came from the Upper Cretaceous of Montana.

Tyrannosaurus must have been a terrifying creature in life (fig. 47). Its head was over four feet long and was slightly compressed from side to side. The jaws had formidable teeth sometimes six inches long and an inch wide. The power of these jaws and the strength of the teeth must have made *Tyrannosaurus* a match for any contemporary. But it was a giant in stature as well, for its great head was set upon a short neck and heavy body and the whole animal was up to forty-seven feet long from the tip of its snout to the end of its tail.

A great deal is known about *Tyrannosaurus* except for the fore limbs, but the indications are that they were specialized for a life of hunting. The remains of this dinosaur have been found associated with remains of the armoured herbivorous quadrupeds of the time, and there can be little doubt that it was upon the herbivores, alive or dead, that the carnivores preyed. That verb is perhaps flattering, for there is little indication in the forms of the brains that are known to indicate any high mental processes. Even the greatest of the dinosaurian flesh-eaters was guided by sight and smell rather than by the careful and thoughtful tracking characteristic of the great mammalian carnivores.

Tyrannosaurus was the climax in the evolution of the Theropods, and its mechanical efficiency was of a high degree.

All the Cretaceous Theropoda did not, however, run to size. There was a sideline of smaller animals, each specialized in some peculiar way. One of these is a favourite with the artists who make reconstruction pictures and it has been called *Struthiomimus*, the ostrich-mimic (fig. 48).

It was thirteen feet long, with a long and graceful neck, a comparatively slender body, and a long thin tail. The hind limbs were long and slender and are suggestive of speed; but the fore limbs also were long, with specialized hands of three fingers with long claws.

There has been a great deal of controversy about how this dinosaur looked in life and how it lived. The latter question has stimulated many imaginations, for here is a Theropod which has no teeth! In some related but earlier forms the dental series was

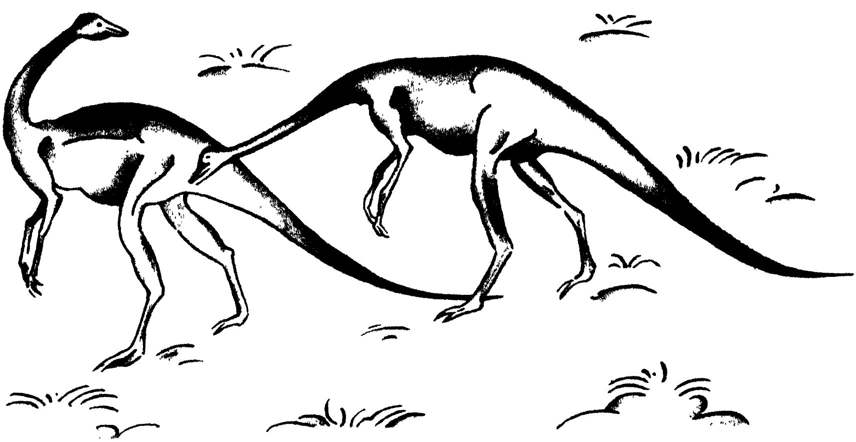


Fig. 48 THE OSTRICH-LIKE STRUTHIOMIMUS
A Cretaceous American dinosaur about thirteen feet long

reduced, but there were no teeth at any stage or age in the life history of *Struthiomimus*.

The animal must have been a typical biped whose balance was excellently maintained by the long tail. It could, no doubt, travel quite quickly if it were pursued, and this speed was probably an inherited character of no value in obtaining its food. It has been suggested that it ate shell-fish, the grinding of the shells being done by pads developed in the jaws, but there is no evidence for this. It is much more likely that the long neck helped the dinosaur to reach vegetation or fruit in small trees and that the specialized grasping fingers could be used to strip vegetation or to peel fruit. This is a more likely explanation and one that the anatomy of the dinosaur supports without invoking the aid of undiscovered elements.

It is doubly interesting because, if this is true, then *Struthiomimus* is the only vegetarian among the Theropoda; and it is noteworthy that an animal so late in the Theropod evolutionary scale should be quite without teeth. This, however, is a feature associated not only with old age in an individual but also with old age in a family or

group of animals and its special significance is dealt with in the last chapter.

If the Theropoda were among the most highly developed in tooth and claw of all animals we know, their relatives the Sauropoda were the most highly developed in weight of land animals of all time.

Their remains have been found only in the Jurassic and Cretaceous and this suggests that they were probably derived from another line of dinosaurs somewhere in the Trias. There is a good deal to be said for their derivation from a cumbrous and primitive form like *Plateosaurus* with whose description we opened this chapter.

Attention was drawn to the bulk and the ungainly limbs of this creature, in both of which rather unattractive features it resembled the Sauropods. There has been an assumption by many that the Plateosaurs were adapted for catching and eating fish and aquatic reptiles in the pools and rivers alongside which they lived. From this it is an easy, if not provable, step to imagine some Plateosaurs spending most of their time in the shallow waters, returning to the land to sleep or to lay their eggs.

For clumsy and lazy animals such as these (and their laziness was engendered as much by their anatomy as by their physiology) life in the water had three prime advantages. In order of instinct these can be listed as, (1) abundance of easily obtainable food, and we have already presumed they were used to that kind of food; (2) safety from their heavy carnivorous enemies, who were not attracted to food in the waters or adapted to pursuing it there; and (3) buoyancy of the water, which eased the burden of the flesh and made possible an increase in body size whether this was desirable or not.

At any rate, when we find the remains of true quadrupedal Saurischia, they show that some such developmental process took place. The skeleton is mechanically adapted for such a form of life. Their skull and jaws are modified for life in the water and for a diet of water vegetation. Since they survived and multiplied and were diverse they must have enjoyed a large measure of immunity

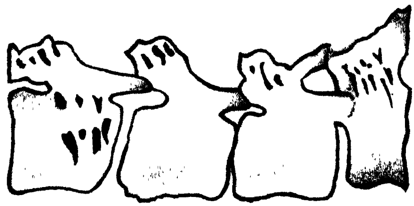


Fig. 49 VERTEBRAE OF BRONTOSAURUS SHOWING THE TOOTHMARKS OF CARNIVOROUS DINOSAURS
After H. F. Osborn

from the great and rapacious carnivores of their time, and, as for bulk, the actual remains testify to the extraordinary size and weight that they attained.

There is also a certain amount of collateral evidence, such as the footprints and the place of deposition of the bones, that helps to complete the picture of this almost fantastic piece of Life's history. Problems there are in plenty, but they are interesting problems, and we can best discuss their positive features by describing three or four of the best-known kinds of Sauropods that give a reasonable picture of this great reptilian company.

One of the earliest Sauropods to be described was *Cetiosaurus*, 'whale-reptile', from the Jurassic of England. It was not known by any complete skeleton but only by a few and scattered remnants, and Sir Richard Owen, when he described and named it, thought it was a monstrous crocodile. This is not so far from the truth as at first might appear, for judging by the skeleton, the dinosaurs and the crocodiles are fairly closely related, and we have already seen that they shared the same 'grandfather' in the Thecodonts.

Since Owen's day more of the English Cetiosaur has been found, and one especially valuable discovery, in the Oxford Clay (Jurassic) near Peterborough, was the right fore limb, the left hind limb and the associated tail. The height of the hip region is ten feet six inches and from this it can be presumed that the total length of the whole specimen in its original state must have been no less than sixty feet. Other specimens from Peterborough include the bones of the end of a tail bearing unmistakable evidences of rheumatoid arthritis.

Various bones of an allied dinosaur, *Ornithopsis*, have been found in the Isle of Wight and the vertebrae are remarkable for the way in which they show how strength and lightness were combined in the huge Sauropod body.

Fig. 50 THE GREAT AMPHIBIOUS DINOSAUR DIPLODOCUS
The largest known land animal, with a length of about ninety feet

The skull of neither of these forms has been found, but isolated teeth have been identified which are only feebly developed.

Amongst the dinosaurs, as in many other groups, it is from the richer store of remains discovered in the United States that the best-known examples of this kind of life have been described and reconstructed.

Brontosaurus is one of these and it has been very fully and painstakingly studied. Its name means the 'thunder reptile', on the presumption that it made a thunderous noise as it walked, which is, incidentally, probably incorrect when one comes to consider its mode of life.

The best-known skeleton came from the Upper Jurassic of Wyoming and the procedure that had to be adopted by its finders illustrates the care that is attached to such studies and consequently heightens the authenticity of the results.

The excavation of the bones in the field took a year, but even so they were still surrounded by much adhering rock material. The most careful work in the laboratory, to ensure that none of the bones was damaged in the cleaning process, occupied a further two years. Even so, the possession of a complete series of bones is no guarantee that their association, the putting together of the material into a reasonably accurate skeleton, is a simple task. At the date in question, nearly fifty years ago, dinosaurian knowledge was still in its youth. The scientists therefore decided to dissect some of the larger modern reptiles to study the relationships of the muscles and joints. With this knowledge they eventually erected the skeleton, having worked out with paper muscles the mechanical implications of the pose that they were to adopt, until, seven years after the field work had been completed, the skeleton was mounted and exhibited in the American Museum, New York.

The resulting skeleton is at first sight grotesque, yet the examination of its mechanics vindicates its constructors. The head is ridiculously small; the long neck has been the subject of cartoons; the great 'slab-sided' body is short compared with the neck and long tail; the ribs, the four pillar-like limbs and the tail all have heavy bones. In contrast, the great bones of the vertebral column

are so excavated that they consist essentially of plates and struts of high engineering efficiency. They could stand the stress and strain of a great body in life (fig. 49).

The limbs introduce some problems and their poise has been the subject of controversy. These dinosaurs have, for example, no knee cap, and the musculature, especially that holding the great bones in flexible continuity, must have been modified for this. Yet they lived, most of them, for a considerable time and in apparent concord with their surroundings, so that their processes did work whether we understand them or not.

Brontosaurus, for all his alleged thunder, was only sixty-five feet long, or perhaps a little more. Yet a larger form, also American, is well known and was ninety feet long. This is the famous *Diplodocus*, a friend of the cartoonist and of some imaginative authors. Even today there is a series of advertisements that features this enormous creature as a domestic problem of the Stone Age. Happily or otherwise for the inhabitants of those times it was not so. The last Sauropod had been dead for a hundred million years before the first man blinked towards the rising sun.

Diplodocus is a well known, if frequently mispronounced, name that means very little to anybody, for the translation is 'double-beam' and refers to a little set of twin rod-like bones on the underside of the tail vertebrae that served to protect these vertebrae, and the vessels near them, as the tail was dragged along the ground. They were, in short, tail skids.

The skull is an interesting object lesson (fig. 51). It is like that of a horse in shape and in size but to attain lightness it has a series of large openings. The large eye openings are conspicuous and on each side, immediately behind and below the eye, are a pair of openings (upper and lower lateral temporal vacuities). Just in front of each orbit is a longish opening (the antorbital foramen) and in front of this there is on each side a smaller opening (maxillary foramen) that is often, not unnaturally, taken for the nostril opening. This is not, however, the nostril, for we find that in *Diplodocus* the nostril openings are together in one large foramen right on the very top of the skull! This remarkable feature should be noted.

Fig. 51 THE SKULL OF DIPLODOCUS, SHOWING THE NASAL OPENING ON TOP OF THE HEAD

If, using the same picture, we look at the jaws, we notice that they are feebly developed, and that there are no teeth towards the back of them. The teeth are a feeble row of lead - pencil - like structures arranged, in both upper and lower jaws, along the front margins and running but little to the sides. They are, in effect, an upper and a lower rake.

It is obvious that in such a skull the power of sight and the apparatus for breathing and smelling were probably well provided for. It is equally obvious that there was little room for a large brain. The braincase has been studied and the brain was about the size of a hen's egg; and it must be remembered that it was only a reptilian brain, not a highly organized cerebral mechanism.

The neck was long and presumably flexible and its vertebrae are elongated structures reminiscent of a miniature Forth Bridge. The body, in contrast, was comparatively short and has only ten vertebrae in its support, which is the lowest number of such vertebrae in the dinosaurs. The tail is very long, thick towards the body, but ending in a sort of whip lash.

The limbs are like pillars of bone, articulating on cartilaginous surfaces that are not preserved. The front legs are shorter than the hind, and the feet were all broad, as well they might be with such weight upon them. Some of the toes in both feet had claws.

That is a brief sketch of *Diplodocus* and its probable appearance in life is shown in fig. 50.

How did this monstrosity, nearly ninety feet long, perhaps thirty tons in total weight, live and move? It is difficult today to visualize as a living organism a creature as large, and of about the same length and weight, as three London omnibuses, yet there is

no question of the reality of *Brontosaurus*, *Diplodocus* and the others.

We have seen something of the nature and organization of the skull. The body has some peculiarities as well. We have said that the vertebrae combine great lightness with obvious strength, but if we analyse the distribution of bone in the skeleton a suggestive feature emerges. All the bone above a line joining the shoulder girdle and the hip girdle is light; and all the bone below this line is heavy.

Now, although those dinosaurs were probably partly terrestrial, it is difficult to consider them as pursuing an herbivorous existence like an elephant. Their limbs are just not adapted to a rambling gait on the land and they certainly give no indication that a sprawling attitude on the ground, like that of a lizard, could be assumed. Furthermore, the teeth are not adapted for biting off leaves from trees, or nibbling at vegetation, though the length of the neck would allow these actions. The clawed feet could not assist in digging up vegetation for they would be needed on land to support the great bulk. How *Diplodocus* must have yearned on land for something to 'take the weight off its feet'. What an advertisement for foot baths it would make!

In that word bath we have perhaps the clue. If these giant dinosaurs went into the waters of rivers, lakes, or estuaries, how different the position would be. The great weight would at once be taken off their feet by the buoyancy, but that is in itself a difficulty. The bather wades into the water; soon the buoyancy affects him, but it takes not only some weight off his feet, it takes him off the ground as well. The diver knows this and has lead on the soles of his boots. We have seen, however, that below a certain important structural line, these Sauropods had heavy bone; above it they were light. So they had the equivalent of lead on their boots. It can hardly be a coincidence. Nor can it be a coincidence that they also had raking teeth that could pull in the vast quantity of vegetation, of water weed, that they would eat.

Thus isolated from the shores by deep water, they were secure from enemies, eased of weight, supplied with food, and, if they

went into deeper water still, so long as the very top of their head was above water their air supply was ensured.

There are, of course, objections to this. They were reptiles, so what about laying eggs? Again it is just possible that, like some snakes and some other aquatic reptiles we shall describe later, their young were born alive. On the other hand, great size is often accompanied by a reduction in reproductive activity. The young are fewer in number, take longer to produce, and births are longer spaced. If *Diplodocus* had to leave the water, it might not be very frequently and he, or rather she, could probably just make the terrestrial grade.

It is hard to imagine this great bulk, and all its physiological processes, controlled remotely by the tiny brain. It is not necessary to imagine this, for a feature not observable in a reconstruction, or even in the mounted skeleton, is the presence of a 'sacral' brain. This was a large nervous centre in the sacral vertebrae, above the hip region, and just below where *Diplodocus* would have lumbago (and it is quite possible that it did).

This second nerve centre, much larger than the brain, apparently controlled the locomotion, and the movement of the tail. It was not altogether a second brain, capable of the second thoughts that even we would like; an organ that gave the answer we all can think of when it is too late! The actual cerebration, such as it was, came from the hen's egg affair in front, and the second nervous mass occurred where the nerve trunks from the hind limbs joined the spinal cord.

This, then, is a more satisfactory picture of these great monsters of the primeval. Harmless monsters, doomed from the start by the appetite, the weight and the mentality of a Dickensian super-fat boy. In their watery fortresses they stood and ate and sometimes just stood. Heavy limbs kept them upright, strong claws kept them anchored, the tail served a fixing and additional balancing function.

How much they ate will ever be a mystery. They were cold-blooded and their metabolism, the amount of fuel they needed and what fuel they got, and how quickly they used it up, cannot be assessed on modern statistics. We have no Sauropods today. We

shall probably never see their like again. Yet, for long years they existed, but after a time they all died away leaving no descendants.

Their disappearance is perhaps less of a mystery than anything else. Huge bulk goes with relatively few offspring, so, comparatively, they would never be very numerous. If geographical changes took place, if their favourite water pools dried up, they had neither the wit nor the ability to search elsewhere. A wiser generation might have carried on, but Sauropods were not wise, even with a second 'brain'. Brawn and real brains do not often go together.

The second great group of the dinosaurs is called the Ornithischia ('bird-hips') from the arrangement of the bones in the pelvis or hip girdle. In these forms it was quadri-radiate, as the lower front bone, the pubis, had two branches, one directed more or less horizontally forwards, and the other downwards and backwards alongside the ischium. In the Saurischia the arrangement was tri-radiate, and from this and some other facts it is certain that the Ornithischia and the Saurischia were separately derived from the Triassic Thecodonts.

Like the Saurischia, which we have just reviewed, the Ornithischia also developed bipedal and quadrupedal forms, but both of these were herbivorous. In the Sauropods we saw that the teeth in the jaws were confined to the front of the mouth, but in all forms of Ornithischia, as we shall see, when reduction in the dental series took place it was at the front of the jaws. Almost all Ornithischia had teeth in the back of the jaws, but in many of them a horny beak was secondarily developed in the front of the mouth.

The bipedal Ornithischia are known as the Ornithopoda ('bird feet') and the quadrupeds are known by the general, if not quite accurate, term of Stegosauria ('plated-reptiles').

The Ornithopoda are well represented in England, particularly in the Wealden deposits. These deposits were laid down in an extensive lake that spread during early Cretaceous times from Belgium and France to the west of England. This lake covered most of Southern England and the Isle of Wight; it contained the bones and other evidences of the life that flourished on and near its shores as in the course of time these remnants were carried into it

by streams and incorporated in its bed. The Weald of England, France and Belgium thus today keeps on revealing traces of that ancient fauna and flora.

In this respect the Isle of Wight has proved a remarkably rich hunting ground and a high proportion of the Wealden dinosaurs of importance has so far only been found there.

One of the primitive Ornithopods is known as *Hypsilophodon* ('high-crested-tooth') on account of the nature of its teeth, which extend along both the front and the sides of the jaws. This is a primitive character among the bipedal group. The hands and feet of *Hypsilophodon* are rather primitive too in that the hand has still five fingers and the foot has four functional toes and the vestige of the fifth. The skin of the animal appears to have had a protective armour of thin bony plates.

The adult dinosaur was about five feet long, the skull taking up about six inches of this length. Almost complete skeletons of both adults and young are known, and some controversy has been aroused about their mode of life. Some authorities have argued that they were primitive armoured forms, as indeed they were, but the thin armour could have given little protection and the hands and feet do not suggest a habit similar to the larger armoured forms.

Hypsilophodon was a vegetarian and the structure of its hands and feet suggest, but can hardly be said to prove, that they could be used for grasping. The modern opinion is that this little dinosaur found its food and security from its enemies in the trees. It was arboreal in the sense that some modern mammals, such as the tree-kangaroos, are.

This dinosaur, attractive though it is, cannot vie in importance or historical interest with its larger Wealden relation, *Iguanodon*.

Iguanodon has been known, in part, for a hundred and twenty-five years. Its discovery actually preceded that of *Megalosaurus* but the latter was described in 1824 at a time when the identification of *Iguanodon* was still in progress.

The teeth were first found in 1822 by Dr. and Mrs. Mantell, who were assiduous and discerning collectors in Sussex. Dr. Mantell was a well-known Lewes medical practitioner and a good

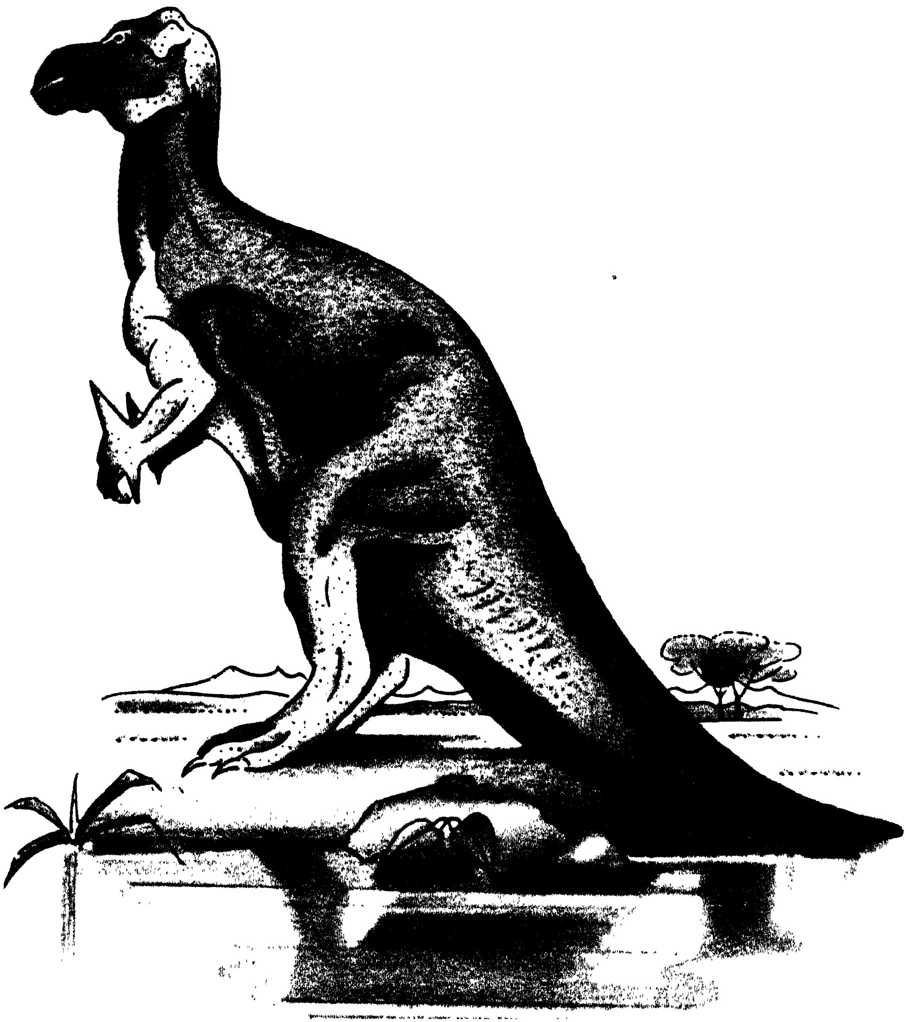


Fig. 52 IGUANODON
An herbivorous dinosaur from the Wealden of England and Belgium. Total length about thirty feet

anatomist, but he could not identify the teeth. Later, other bones were found that were obviously related to the wearer of these teeth.

As all these bones were of an intriguing nature and size they were sent to Baron Cuvier in Paris, one of the greatest comparative anatomists. Cuvier identified one set of bones as being those of a rhinoceros and another set as having belonged to a hippopotamus, though he later admitted his errors of judgment.

Eventually, however, the similarity of the teeth of the fossil with those of a modern lizard, *Iguana*, was pointed out by Mr. Stutchbury of the Hunterian Museum of the Royal College of Surgeons in London. Hence the new fossil was named '*Iguana*-tooth', that is, *Iguanodon*.

Since that day numerous discoveries of bones and footprints have been made. The outstanding event which revealed the true nature of the dinosaur took place, however, in Belgium, where, in 1878, the workings in a coalmine ran into an old, filled-in ravine containing no fewer than twenty-nine Iguanodons. Some of these skeletons were not in good condition, others were excellently preserved, and all contributed to a complete picture of the dinosaur. About twenty-five years ago an almost complete skeleton of a smaller individual was found in the rocks at Atherfield, Isle of Wight.

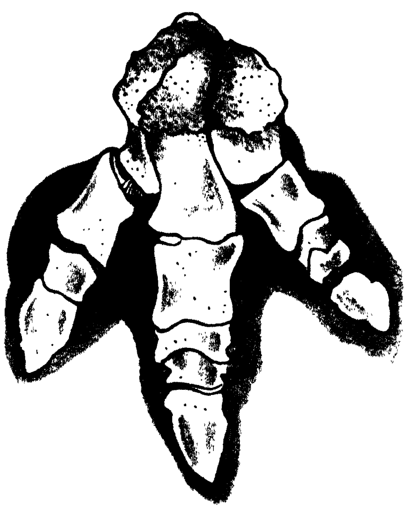


Fig. 53 FOOTPRINTS OF IGUANODON FROM THE WEALD OF SUSSEX

The largest Belgian forms measure nearly thirty feet from the snout to the end of the tail. The skull is about the size of a horse's head, but is compressed a little from side to side and has no teeth in the front of the mouth. Horny beak-like pads were developed at the front of the jaw instead. The teeth are spatulate, serrated and rather leaf-like, and were obviously used to

chew leaves and such small branches as the beak could nip off.

The skull was borne more or less horizontally on a moderately erect and shortish neck. The body was compressed from side to side and ended in a deep, strong, compressed tail. The balancing function of the dinosaur tail is here admirably demonstrated, for on the vertebrae connecting the body and the tail there can still be seen the remnants of the tendons, which were so important as strengthening structures that they had become ossified.

The hind legs were stout and supported by massive bones. The feet had four toes but only three were functional, as is proved by the footprints that are found quite frequently (figs. 5 and 53).

The fore limb was about half the size of the hind, ending in a five-fingered hand. The thumb is a bony spike that may have been used as an offensive or defensive weapon, but which was more probably used to dig branches off trees. This thumb-spike was placed upon the nose in some early reconstructions.

In repose, resting upon its hind limbs, *Iguanodon* must have resembled a kangaroo (fig. 52). In motion it was probably quite a swift runner, and the tail, flattened from side to side, suggests that it may have been of assistance if the dinosaur went swimming. It may well have taken to the water to put itself out of the reach of its carnivorous pursuers and also to cross rivers to pastures new.

Certainly some dinosaurs of a closely similar nature were adapted for a more or less amphibious life. Some good skulls and skeletons of these forms are known from the United States. The principal animal involved is called *Trachodon* ('rough tooth') since its teeth were arranged in a very peculiar block.

Trachodon resembles *Iguanodon* in several ways, and a skeleton of this kind, found in a suburb of Philadelphia, was the first dinosaur skeleton to be found in the United States. At first sight it looks like a modified *Iguanodon*, the modifications being in the skull, the feet and the hands.

The skull is long and flattened and ends in a duck-like bill, so that the group or family of dinosaurs to which *Trachodon* belongs is known as the Duck-billed Dinosaurs. The nostrils, instead of

being near the tip of the snout, are half-way up the face behind the bill. The eye was strengthened by sclerotic plates.

The most remarkable thing in the head is the series of teeth. The jaws are well provided with teeth, but not of the nature to which we have become accustomed. For each side of the jaws has up to sixty vertical rows containing ten to fourteen successional teeth, that is, there were about three thousand teeth altogether. The whole formed a pavement of closely adjoining teeth.

As the tooth pavement was worn down by the hard siliceous plants that formed the food, so the working layer was gradually worn away and immediately replaced by the upward growing successional teeth. As the upper and lower jaws worked obliquely upon each other, the arrangement might be described as a slow-moving dental escalator, with the lower and upper escalators always just managing to make contact. It can be presumed from the need for such an arrangement that the Trachodonts probably lived upon the hard horsetail rushes that were quite common in these Upper Jurassic days.

The fore limbs had a four-fingered hand, for the thumb is missing here. This hand was webbed, and there is no doubt at all of this, for one of palaeontology's most interesting finds was a mummified *Trachodon*. The skin, of course, had disintegrated millions of years ago, but the perfect impression of it was left. This showed clearly the webbing of the hand and also showed some kind of pattern in the skin that was perhaps a colour pattern. *Trachodon* was very probably darker on the back than on the belly, as many modern reptiles are.

The strong hind legs had three-toed feet. The presence of the beak, the backwardly placed nostrils, the webbed hand, and the compressed tail are all signs of a water-living existence. These signs, if suggestive in the case of *Trachodon*, are insistent in the case of its later Cretaceous relations, for they became 'helmeted', developing a grotesque series of bony cock's-combs, crests and great spikes on the skull. The appearance of these excrescences is odd enough but it is the more curious that they are principally developed from the grossly enlarged nasal bones.

As the outgrowths are hollow it is difficult to avoid the conclusion that they were associated with the air passage and that they were thus used in diving.

We can, therefore, in imagination picture *Trachodon* in the waters where, aided by their 'diving bell', the related forms submerged themselves amongst their larders of aquatic vegetation (fig. 54).

From time to time we have stressed the grotesque variations, the peculiar developments of bone, that accompany the later stages of many fish, amphibian and reptile groups. These air passages, so remarkable in form, were perhaps such 'bumps', though in this case they could be used.

Fig. 54 THE DUCK-BILLED DINOSAURS: TRACHODON IN THE FOREGROUND AND CORYTHOSAURUS IN THE WATER

Their remains are found in N. America. Trachodon was about twenty-nine feet long

Another group of Ornithopodous dinosaurs, however, developed the bumps only to a ridiculous degree.

For many years a peculiar American dinosaur called *Troödon* has been known. For a good many of these years it has been alleged that the skull of this creature was put on the wrong body, for, whereas the body was quite similar to that of many other Ornithopods, except that it had abdominal ribs, the skull was very like the skulls of some armoured dinosaurs.

It now appears that the two, skull and skeleton, are correctly associated, and that we have here a bone-headed dinosaur in the literal sense of that much-used term.

Troödon, with his domed skull, was quite a small fellow, about six feet long altogether, and he probably lived on the higher ground above the marshlands, which helps to explain why his remains are not so frequently found. The jaws had teeth even in the front and this, coupled with the fact that the number of digits in his hands and

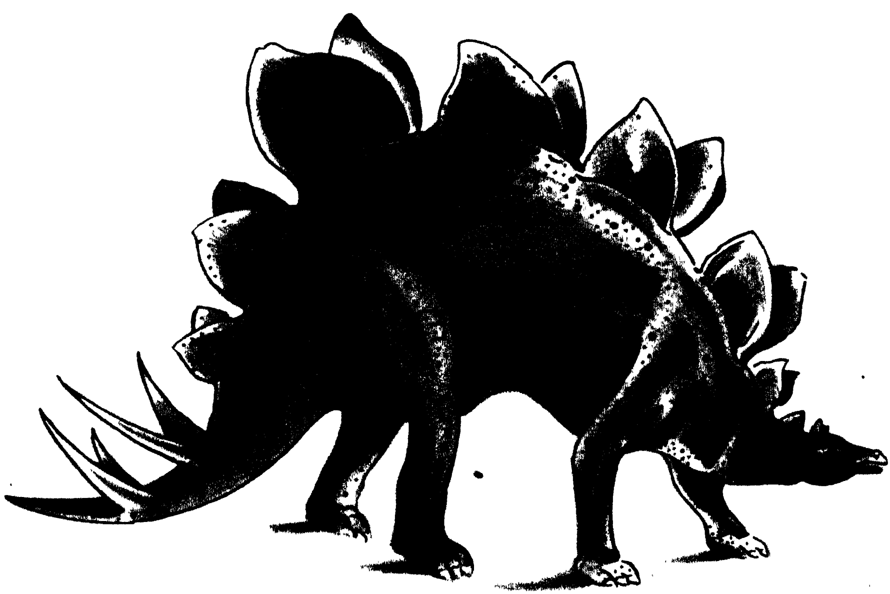


Fig. 55 STEGOSAURUS
An armoured dinosaur with alternating plates on the back and spikes on the tail. Length about twenty-five feet

feet were but little reduced, suggests that he was a late survivor of a primitive, unspecialized group. However, things went to his head with a vengeance. But if *Troödon* was a bone head, his relative of the late Cretaceous, *Pachycephalosaurus* ('thick-headed-reptile') was a super-bone head (fig. 82).

The skull of this fantastic little dinosaur was nearly solid bone and even then the outside was ornamented, or encumbered, by bony bosses and spikes and small ossicles. This is boniness gone mad, for the heavy skull had only a little brain case and all above it was solid bone. Grotesque, pathetic little dinosaur, his race as well as he was doomed, and the last days of the Cretaceous saw the last of all these dinosaurs.

The last group of the dinosaurs, the armoured forms, or Stegosauria, were bony from the start. Like their bipedal, Ornithopodous relatives they were all vegetarians; they were like the Ornithopods also in that, where tooth reduction took place in the jaws, it was at the front, and there was developed, in place of the teeth, a large, horny, bird-like beak.

They were all slow-moving reptiles using all four feet for locomotion. They differed mainly in size and in the particular type of armour that was thrust upon them.

They were perhaps the gentlest of the dinosaurs, under a lifelong, bony bond of non-aggression. One of the best-known examples as well as one of the most ridiculous aesthetically, is *Stegosaurus* itself, from which the whole array usually take their name of Stegosauria.

The oldest of them that we know came from the Lower Lias (Jurassic) of Dorset in England and is known as *Scelidosaurus*. From then until the close of the Cretaceous they are, in one form or another, always in the dinosaurian picture.

They were never very large, the greatest of them being perhaps thirty feet or so in length. Practically all of them were terrestrial, for obvious reasons, but one or two have been thought to have ventured occasionally into the waters.

Their origin, though uncertain, was probably in some comparatively simple Ornithopod, and may well have been in an

ancestor common to the bone heads mentioned above, and probably in the *Hypsilophodon* line of descent.

Stegosaurus itself has some features of great interest. In size specimens vary from twelve to thirty feet and in the largest the hip region was about five feet from the ground. Its head was ridiculously small compared with the massive body. Of the limbs supporting that body, the front legs were borne on five-toed feet,

Fig. 56 AN ISLE-OF-WIGHT DINOSAUR, POLACANTHUS FOXI, WITH ITS PECULIAR ARMOUR

Length about fifteen feet

and the hind limbs, about twice the size of the front ones, had feet with four toes, although only three were in use.

The armour consisted of a series of upstanding, flattened, bony plates, sometimes thirty inches high (fig. 55). During life these plates were covered with horn so that they would be even larger, though some of the height would be lost as the bases were embedded in the skin of the back. There was no more secure fixation than that. The number of such plates was twenty to twenty-two and they were arranged over and along the backbone in two rows of *alternating* plates. Behind the plates, towards the end of the tail, were two pairs of spikes, considered by some as weapons of offence. Elsewhere there were particles of bone scattered about the skin.

As a defensive arrangement this armour would appear to be farcical. Any of the great carnivores of the time could mortally wound the Stegosaur or tear off a limb without being obstructed by the dorsal plates. The tail appears to have had little flexibility sideways so that the four spikes would be of doubtful value as a weapon.

The teeth are apparently suited to a diet of succulent plants, so these grotesque animals probably wandered by the side of the lagoons where the Jurassic Sauropods were wading. They had more in common with them than mere contemporaneity, for we have seen that some of the Sauropods had two so-called brains; one in the head and one in the sacrum.

Stegosaurus outdid them in this, for it had an additional one, a shoulder-brain as well. The actual brain in the skull was fantastically small; not only small in size but small in weight and in organization. Its size was approximately that of the brain of a small kitten but of quite low efficiency in comparison. The cavity in the shoulder region for the spinal cord was enlarged to a small degree for a nervous ganglion that has become known as the brachial enlargement or 'brain'. The cavity in the sacrum, however, for the sacral enlargement or 'brain', is relatively large and this nervous mass was about twenty times the size of the brain in the skull.

The real brain was the centre of reception for the stimuli of eye, nose and ear, and passed them on. The shoulder enlargement was, more or less, in charge of the fore limbs, while the sacral enlargement

looked after the hind limbs and the tail. This is not a surprising delegation, for the largest of these animals must have weighed ten tons, and pushing this animated tank around the grasslands must have been a whole-time task. These so-called brains are merely the enlargements of the spinal cord where the nerve trunks from the limbs join it. They are also seen in Man.

The Stegosaurs were all Jurassic but they were surprisingly widespread; remains have been found in England as well as in various parts of the United States.

A unique example of a similar kind of dinosaur was found many years ago in the Wealden of the Isle of Wight. Unfortunately the remains are tantalizingly incomplete, and the skull and fore limbs are quite unknown. The elements of the armour are, however, well preserved, though there is some doubt as to the precise position of some of them.

The main feature of this armour is a large quadrangular plate of bone that rested over the hip region, somewhat in the manner of a backwardly placed saddle-cloth. This buckler is composed of a number of irregular plates of bone of different size that have become fused together. In front of the buckler there were two series of long sharp spines that probably ran along the neck and the body, one row to each side, with the points of the spines directed outwards and a little above the horizontal. The tail carried no spines and, instead, had two rows of broad, sharp-edged plates, with little ossicles in the skin that separated them.

As the hind feet are also missing, the exact adaptations of this peculiar dinosaur cannot be accurately assessed. In life it was probably fourteen or fifteen feet long and about four feet high at the sacral buckler. The bones bear evidence that the muscles attached to them were strong, and the presumption is that *Polacanthus*, as the animal is called, was a heavy, slowly moving vegetarian. A reconstruction of its probable appearance in life is given in fig. 56.

The maximum development of this kind of heavy armour that we know is seen in a single specimen collected from the Cretaceous sandstones of the Belly River in Canada. It is unfortunate that in the difficult task of excavating it from a precipitous bank of the

river the skull was not extracted. The specimen was duly cleaned up and prepared for exhibition and it was during this process that traces of the original armour were discovered. A very careful dissection of the rock matrix was made with the result that we now know the skeleton and skin armour of this dinosaur with some completeness.

The armour consists of different kinds of bony development. The neck was protected by two transverse strips of bone separated by a little band of flexible skin. This neck plate was collected as the skull, a very understandable error. Behind this is a broad belt of tough skin indented where the fore limbs meet the body, and behind this belt come four transverse strips of rigid skin separated from each other by narrow belts of flexible skin. These strips covered the front half of the body, and the hinder half was protected by a rigid plate obviously formed from three fused strips of a similar nature to those of the front half. All these strips bore bony spines running in longitudinal rows from the neck to the tail. The end of the tail had two massive spikes (fig. 57).

During the animal's life these spikes would have a horny covering and, as the fore limbs had a battery of small, sharp spikes for protection, this dinosaur must have been a spiny and bony 'tank'. The

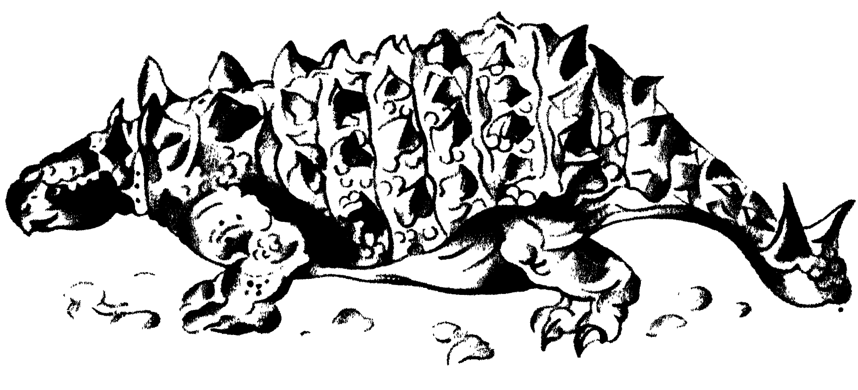


Fig. 57 SCOLOSAURUS

The most heavily armoured dinosaur known. About nineteen feet long, the remains have been found only in Canada

armament went even further for the skin was impregnated with ossicles. On account of its spikiness the dinosaur is called *Scolosaurus.*

The fore limb is shorter than the hind limb, and this heavy animal must have moved upon sprawling limbs. In the sprawling condition it must have been a difficult animal to attack, for every part of it except the hind legs, was adequately protected. It is even possible that the hind legs were safe, because the heavy tail with its formidable spikes could perhaps have been swung round.

The complete dinosaur must have been about nineteen feet long, eight feet broad, and four or five feet high. It probably weighed about six or seven tons, and was the most heavily armoured dinosaur of which we have evidence.

As the skull is still in a cliff in Canada, we know nothing about the teeth. We do know, from the evidence of the sandstone enclosing the body, that it lived in a sandy region rather like a river delta. That trees occurred nearby is proved by the perfect preservation of a plane leaf on the skeleton. The presumption is that *Scolosaurus* was a plant-eater, although the suggestion has been made, on the analogy of some spiky, desert-living modern lizards, that it was insectivorous.

How far the development of armour was a true protection, and how far it was just bony development, is difficult to say, but it appears clear that *Scolosaurus* is the final product of the *Polacanthus* line of spike and plate growth.

The last dinosaurs we need mention are also armoured but in a totally different way. They had, it is true, spikes and plates of bone but none of these was upon the body. The body was large and rhinocerine but unarmoured with bone, and the great bony development was in the skull. The typical dinosaur of this kind had three well-developed horns, one over each eye and one over the nose, and the back of the skull was produced into a great bony frill over the neck. Because of the three horns over the face it has been called *Triceratops.* The group containing these kinds of dinosaurs is accordingly known as the Ceratopsia.

Triceratops itself (See Frontispiece) comes from the Upper

Fig. 59 THE EGGS OF PROTOCERATOPS
A horned dinosaur from the Gobi Desert of Mongolia.
The eggs are six inches long

Cretaceous of Wyoming in the United States. The whole animal was about twenty-five feet long, with a body like a rhinoceros, but with a skull six feet long, ornamented by the three horns, and the long frill over the neck, that we have already mentioned. The front of the mouth had a horny beak developed and the teeth, restricted to the back of the jaws, were adapted for chewing vegetation.

Apart from the size, and the shape and ornamentation of the skull, there was nothing very remarkable about these creatures. We have seen so many bizarre forms of dinosaur that these are almost homely by comparison.

An interesting series of the skulls can be tabulated starting with the small, unhorned, kind from the Lower Cretaceous of Mongolia right up to forms with the frill greatly ornamented by a series of spikes.

The Mongolian form, though unspecialized, is of particular interest for it was the dinosaur that laid the nest of eggs discovered some years ago and illustrated in figure 59.

The whole series of these dinosaurs is well known from numerous examples and, as the eggs of *Protoceratops* have been fully examined, we have a fairly complete idea of this phase of dinosaurian evolution. The braincase has also been examined, and the brain, although larger than that of some of the dinosaurs we have mentioned, is still comparatively primitive in organization.

The Ceratopsians are different from the *Stegosaurus* and *Scolosaurus* kind of dinosaurs not only in the type of armour but in the consequent mode of defence. The latter, plated, kinds were passive. They no doubt dug their toes into the soil and bore the onslaught of their carnivorous enemies after the manner of massive hedgehogs. *Triceratops* on the other hand, could lower his head and charge, or, standing firm, direct his horns at the advancing adversary and expect to impale it on his horns, if it were not too massive. He obviously did so, for some of the skulls of Ceratopsians bear the honourable scars of battle. There are even the evidences of fractures that had subsequently healed, and that were exactly where one might expect to find them if the animals did adopt a rhinoceros kind of attack and defence.

But the days of the Cretaceous were drawing to their close. The attacking carnivores and the defensive herbivores, the amphibious and the terrestrial forms, the bipeds and the quadrupeds, were all faced with a common enemy much greater than themselves.

They were all specialized in tooth and claw, in bulk of body or of bone and were weighed down by years of restricted habit. So that when the changes of climate and vegetation came, and the gradual disappearance of familiar dwelling-places was brought about by geographical changes, the dinosaurs could not adapt themselves to the new demands. They folded their tents like the Arabs and silently stole away.

They left no descendants of any kind. After a racial record of more than one hundred million years they left the field to a few insignificant reptiles, to a handful of birds, and to the little mammals, who almost at once seized their unexpected opportunity. The age of reptiles was over, but the day of mammals had dawned.

CHAPTER XIII

REPTILES RETURN TO THE SEA

In the course not only of these pages but of our ordinary life as well, we are familiar with animals and people who tired of the struggle in a new sphere and went back to the old home with its familiar ways.

Many important forms of life in the past did so too. Some amphibia, as we have seen, abandoned their tenuous grip upon the mud and returned to the muddy pools. As we are all aware, many true birds, in the anatomical sense, remain upon the ground and now cannot fly. Among the familiar mammals, the seal, the porpoise and the whale are all examples of those that have chosen to desert the land.

It is not so easy for the animal to return to the ancestral habitat as for the weary traveller to return home. In both cases much depends upon how long they have sojourned in the far country. For both it may mean much re-adaptation. Among the animals the old swimming structures have been lost; they are never regained, and a new, secondary series has to be developed. The flipper of the seal is not, for example, a revival of the ancestral fish-amphibian type (for that has been for ever lost in the mists of developmental history) but is a new adaptation of the mammalian terrestrial limb.

Thus, the return is no spontaneous event; these reptiles and mammals did not cry, like Xenophon's men, 'the sea, the sea' and forthwith celebrate the return journey. It was a subtle, slow, almost imperceptible process, but they got there in the end. We cannot conclude the history of the reptiles without a reference to the forms that made a successful, indeed in some cases, a spectacular, return to the sea.

The main groups of them were the Placodonts, of the shallow, shoreward waters; the Plesiosaurs of the deeper waters; the marine and free-swimming Ichthyosaurs; and the mighty Mosasaurs, who were very corsairs among the reptiles and sailed the seven seas. Of

these, the Placodonts and the Plesiosaurs belong to the same group and share a common ancestry in the Triassic or Permo-Triassic. The Ichthyosaurs and the Mosasaurs have separate affinities distinct from each other and from the Plesiosaurs.

For the origin of the Plesiosaurs we must turn back the geological clock to the Permian and to our old friends the Cotylosaurs, for from some Cotylosaur there were derived the Protorosaurs ('earlier lizards') which were lizard-like animals with a certain amount of adaptation for life in the water. Almost certainly from these forms came the first of the Plesiosaurian creatures, the Nothosaurs of the European Trias. The Nothosaurs ('false-lizards') are now very well known through a remarkable series of discoveries in the Triassic of Lombardy, and delightfully complete skeletons have been the basis of excellent studies by a Swiss professor, Dr. Peyer.

The principal forms he has discussed are *Nothosaurus*, *Lariosaurus* *Neusticosaurus* and *Pachypleurosaurus*. They differ in their size and bodily proportions and in their adaptation for swimming, but there is no doubt that they were reptiles of the shore, able to run on the beaches, clamber on the rocks and paddle in the sea.

They were small animals, two or three feet long, though *Nothosaurus* was a little larger than this and had a skull nearly a foot long. Their skeleton was rather like that of a little crocodile, but the skull was proportionately broader. The jaws were full of sharp, thinly conical teeth, of different sizes, that are closely similar to those of the later and larger aquatic Plesiosaurs. At least one of these forms had teeth on the palate as well as in the jaws.

The limbs were of the normal terrestrial pattern but the hands and feet were long and were probably webbed during life. The skin was lizard-like and not covered with scales as is that of the crocodiles which these animals strongly resembled.

Another Triassic group of reptiles whose skeletons are very similar to those of the Nothosaurs are the Placodonts ('broad teeth') but the skull of the latter was quite different. *Placodus*, which is typical of the group, had a triangular skull, as broad as it was long, with large openings on the skull roof behind the eyes. The jaws and palate were quite different from those of *Nothosaurus*, for there were

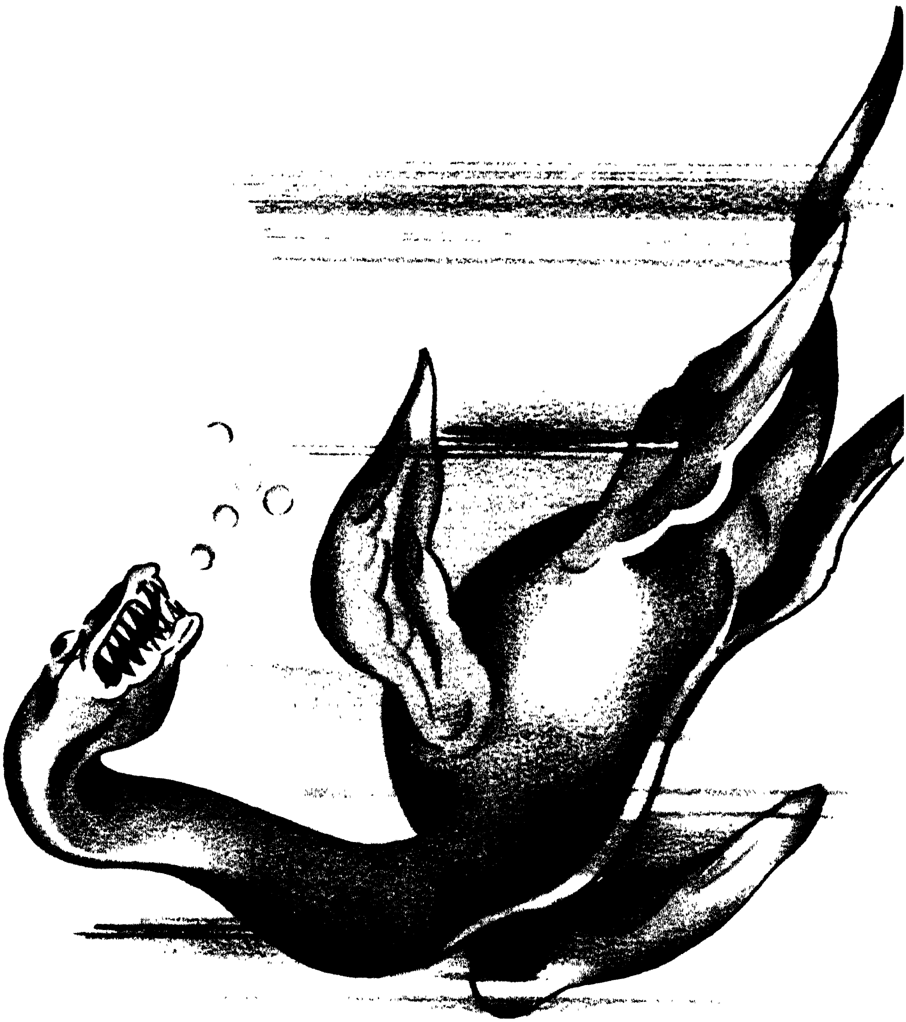


Fig. 60 PLESIOSAURUS
Specimens vary from three to thirty feet or more in length

no sharp conical teeth on them and, instead, they had a small number of broad, domed knobs that must have been used to crush shell-fish.

The Placodonts may therefore be considered to be early Plesiosaurs which had already adopted an independent line, that of cruising around in the shallow waters devouring the molluscs that were abundant there. However successful this kind of life may have been to individual Placodonts, it was not a general success, for they were all extinct by the end of the Trias.

The true Plesiosaurs, as represented by the Jurassic *Plesiosaurus* and the Cretaceous forms, were larger animals on the Nothosaurian plan. They were adapted for a more truly aquatic life and had the limbs modified as paddles. This was accomplished by the reduction in length but broadening of the upper bones in the limbs; the lower bones of the limbs were rounded, but there was a great increase in the number of bones in the digits and in the length of the digits. These bones were held together in a fin that worked on the principle of an oar. The head and neck varied considerably in relative proportions, for some forms had large heads and small necks, while others had small heads and very long necks.

The skull had openings for nostrils, eyes, a pineal eye, and great vacuities behind. The jaws were arranged in slightly different patterns in various groups and in this they resembled the crocodiles. The teeth were sharp and conical, with fine vertical striations on them. They were quite adapted for a diet of fishes and cuttle-fish, as we know from the fossilized stomach contents discovered. The Plesiosaurs were in the habit of swallowing pebbles, too, which were used in the stomach to help to grind down the various hard ingested materials.

The skeleton was built on a solid and efficient plan. The vertebrae were stout with slightly biconcave ends (fig. 31). The shoulder and hip girdles were well developed for the strong musculature that was needed to propel the 'oars'. The ribs were well developed too, and a plastron of abdominal ribs was developed. It was this last character which led Dean Buckland, the Oxford professor, to refer to the Plesiosaurs as 'snakes threaded through the shell of a turtle'.

The skin was unarmoured and apparently smooth and the only accessory structure was a rhomboidal tail fin (fig. 60).

The first Plesiosaur remains were discovered in 1821 by a young woman, near Lyme Regis in Dorset. The young lady was to become well known for her discoveries of the larger fossil reptiles, specimens of which she sold to many an illustrious collector and anatomist. Her name was Mary Anning and she was twenty-two years old when she sold her first Plesiosaur.

Many of the best and most typical examples of the Genus *Plesiosaurus* ('nearer to a reptile') come from the Liassic[1] rocks of England, especially from Dorset, Somerset, Yorkshire and Warwickshire, though fine skeletons, of much the same age, have also been found in Germany.

They all help to fill in the details of a somewhat constant picture of large swimming reptiles, with voracious mouths, that could paddle their way with strong strokes along the surface of the deeper seas. Not only could they paddle with forceful strokes ahead but they could also back water and turn quickly with the aid of their rudder-like tails. This was probably necessary in their pursuit of fish, as their necks, long and graceful as they may have been, were not very flexible, and could not have been used for the thrusting actions that are characteristic of swans.

Anatomically these Plesiosaurs were well adapted for a life at sea but physiologically they were not. They must have had to return to lay their eggs upon the shore for, so far as this function was concerned, they were tied still by their terrestrial legacy. The Liassic Plesiosaurs were large creatures, anything from six to thirty feet long, but some of the later Jurassic forms were also of large size. *Pliosaurus*, whose remains are well known in England from the Oxford and Kimmeridge Clays, had a huge skull, six feet long, but as this was one of the large-headed, short-necked kinds its total size was not so monstrous as might be expected.

During the Cretaceous period Plesiosaurs were spread across nearly all the seas. Some of them, whose teeth and bones are found

[1] Lias, adjective Liassic, is the name of a Lower Jurassic deposit, and is said to be derived from the cockney pronunciation of layers.

Fig. 61 THE MARINE ICHTHYOSAURUS
Of similar size to the Plesiosaurs

in the English Chalk, were huge fellows, with large, strong teeth two or three inches long.

At that time almost fantastic examples were roaming the seas in what is now America. The great *Elasmosaurus* was no less than forty-one feet long. The skull was two feet long, the body nine, the tail seven and the neck was twenty-three feet long! In such forms it is likely that the anterior part of the neck was more flexible and that some kind of darting thrust was possible. In the largest forms, where the neck was obviously stiff and immovable to support a great head, the food could still be captured effectively by the great gape of the jaws.

These great Plesiosaurs were not the only reptiles in the seas; side by side with them there had been developing a parallel order of secondarily aquatic creatures. These were the Ichthyosaurs ('fish-reptiles'). They could claim an older ancestry than their contemporary seafarers, for it seems likely that they were descended from a group of small Carboniferous aquatic reptiles known as the Mesosaurs. These were clearly descended from land-living forms, early descendants of the reptilian Adam, a Cotylosaur.

The Mesosaurs had their limbs modified as paddles, the front paddles being smaller than the hind. They had long heads and bodies; long, that is, considering their total size of two feet, and the jaws had a remarkable series of long, thin, protruding teeth. It is significant that much of the length of the skull is due to the lengthening of the snout, the part in front of the eyes. This is repeated to a marked degree in the Ichthyosaurs (fig. 61).

The typical Ichthyosaurian skull is mostly snout, a long thin wedge of bone whose jaws are lined with thin, sharp-pointed striated teeth, again admirably adapted for catching fishy prey. The eye is large, sometimes remarkably so, and strengthened by a ring of sclerotic plates. There was also an opening for a pineal eye, and the nostrils were just in front of the paired eyes.

Behind the head in the living animal all reptilian appearance was lost. The awkward Plesiosaurian body with its oars is nothing like the streamlined Ichthyosaur, controlled by four fins, with a triangular fin upon the back, and with a great propulsive tail like that of a fish.

It is true that as we look at the skeleton today this fish or dolphin-like aspect is less obvious. The fins are the modified remains of a once terrestrial limb. But the bones of the hand are multiplied and all are fitted together as a mosaic of bone that was held together and strengthened by a cartilaginous pad (fig. 63). In most Ichthyosaurs the fore paddles are larger than those behind.

The tail is of interest because, although superficially it resembles that of a fish, its bony support, of vertebrae, is differently arranged, and it bends *down* and is in the lower lobe of the tail, whereas in the fish it bends up and supports the upper margin.

The fin on the back has no bony support at all, and until actual impressions of the body of an Ichthyosaur were found, no one knew it had ever existed. These same impressions show that the skin was quite smooth.

Ichthyosaurs of various kinds swam in the seas from the Trias till the Cretaceous, like the Plesiosaurs. Both groups were about the same size. They have a historic similarity as well, for the first Ichthyosaur to be known was found, like the first Plesiosaur, near Lyme Regis in England by the same person, Mary Anning, although at this time she was a girl of only twelve years of age (1811).

This first specimen was of Jurassic (Lower Lias) age, but Ichthyosaurs were later widespread and their remains are known from many countries of both the old and new worlds. This is not surprising for they succeeded in casting off completely from the shores.

For many years it was realized that in the body cavity of some Ichthyosaurs there were the remains of small Ichthyosaurs. These little ones occurred in almost any position and it was presumed that they were the remains of a meal of long ago. A close study of these little skeletons has been made in recent years and the striking fact emerges that in every case where identification can be made the little skeleton belongs to precisely the same species as its 'captor'. It seems to put too fine a point on Ichthyosaurian intelligence and taste to suggest that they ate only their very own kind, and it is

Fig. 62 THE GREATEST MARINE REPTILE, MOSASAURUS
About fifty feet long

logical to assume that these little skeletons are not the remains of food but are the remains of unborn young.

Thus the Ichthyosaurs, like many fishes and snakes, would seem to have brought forth their young alive. That is, they were viviparous, but of course, being reptiles, they are not to be compared in this way with the habits of the seals and whales.

Free-swimming, streamlined and voracious, they too roamed the seven seas. They too were shipwrecked in another great mystery of the sea at the end of the Cretaceous, and there were no Ichthyosaurian survivors.

Yet another group of reptiles felt the call of the sea and in this case we can legitimately translate the Greek word *sauros* as lizard, for they were real lizards, descendants and relations of the primitive monitors or varanids.

They had truly lizard skulls, with loosely built jaws, like those of snakes, for swallowing large prey. The eyes had sclerotic plates like those of the Ichthyosaurs and the nostrils were high upon the face. The latter was one of the few truly aquatic modifications, for the vertebrae were those of lizards and the limbs were still largely of the terrestrial type and modified as paddles to a much less extent than those of either Plesiosaurs or Ichthyosaurs.

In the skull the teeth were sharp and recurved and were borne on the palate as well as on broad bases in the jaws.

The living *Mosasaur* (fig. 62) had an unarmoured skin on which some thin scaly covering may have persisted. The tail was long and there is little doubt that it was the principal organ of propulsion. Mosasaurs as well as Ichthyosaurs used their great tails as powerful, sinuous propellers and the limbs acted as keels to ensure a steady course.

Probably the Mosasaurs were not so independent of the land as the Ichthyosaurs, but they must have been very numerous. They only came into the geological story in the Cretaceous, and even then in its later stages, but their remains are known in Europe, America, Africa and the southern continents. Yet the name is derived from the quiet river Meuse ('Meuse lizard') since their remains are common at Maastricht.

They were the true sea-serpents of the past. Often fifty feet long, rapacious and cruel, they were the reptilian climax of the attack upon the high seas. And it failed.

Ichthyosaurs, Plesiosaurs and finally the great Mosasaurs, were flung into attack, but the unknown enemy overcame them. What they thought of each other we cannot know, but in defeat they are not forgotten and their bones remain to us as memorials of a noble attempt. They disappeared but others have remained, the crocodiles and the turtles, uninspiring relations which, since they live today, need no special commendation here.

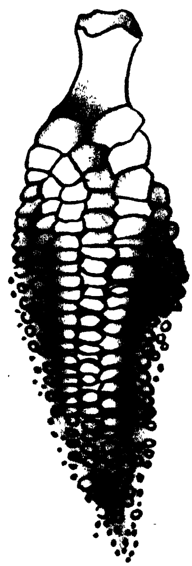


Fig. 63 THE PADDLE OF AN ICHTHYOSAUR

CHAPTER XIV

REPTILES RULE THE AIR

THE reptiles, as we have seen, mastered the lands and the seas during their great evolutionary development in the Mesozoic. There remained one element, the air, to which they might aspire. It was not an unconquered element for the invertebrates had already succeeded, in the insects, in establishing a strong hold upon it.

Yet the vertebrates were not so far represented among the air-borne creatures. The flutterings of fish can hardly be accepted, the amphibians were not apparently interested and, as yet, the birds had not arisen.

The first flying reptiles, the vanguard of the Pterosaurs ('wing reptiles') appeared in the Jurassic, and by a remarkable coincidence, as we shall see in the next chapter, it was during that period that the birds also were evolved. The two are not closely connected, yet both are related to the dinosaurs. The Pterosaurs and the birds were ultimately derived from the pre-dinosaurian stock of the Thecodonts. Yet in general anatomy, wing development and the mechanism of flight the reptilian aviator was very different from his distant and feathered relation.

We need not dwell here upon the history of the discovery of flying reptiles' bones or of the struggles in the interpretation of them. It may suffice to say that, by another coincidence, the first bones of Pterosaurs were found in 1828 at Lyme Regis by Mary Anning, the young woman who had already discovered the first Ichthyosaur and the first Plesiosaur.

The first scientific studies upon the group were made by the great English anatomist, Sir Richard Owen, who can be said to have put vertebrate palaeontology upon its feet in this country.

Anatomically these flying reptiles are all much alike. The skull is rather similar to that of a bird and is reduced in weight through the presence of large cavities, especially those for the nostrils which are placed half-way between the tip of the snout and the large eyes.

Fig. 64 PTERODACTYLUS

The eyes were usually strengthened by a ring of sclerotic plates.

The skull was none the less solidly built in that the bones were usually firmly fixed together and the sutures or junctions between the bones are difficult to determine especially in the face. The occipital condyle, for the articulation of the head upon the neck vertebrae, was single and the position of it clearly shows that in life the head was carried at right angles to the neck as in birds.

The snout was pointed or gently rounded and the jaws were slender. Some forms were toothed, others toothless as in birds, and the latter kind may have had a horny beak or covering developed on the jaws.

The teeth when present were sharp, thin cones, in a definite socket, usually few in number, and well spaced out in the jaws.

The brain cavity has been examined and casts of it have been made. It appears to have been much like that of birds but not so large in proportion to the skull. The development of sight in the

brain was great, associated with the large eye, but the sense of smell, despite the large nostrils, was only feeble. The powers of co-ordination, so important in a flying creature, were well developed.

The bones of the skeleton were adapted for flight. In some forms certain areas of the vertebrae were strengthened to assist the muscles used for flying. The breastbone was specially developed for the large muscles of the upper arms used in flight. There were some abdominal ribs.

The long bones of the limbs were hollowed, as are those of birds, to lessen the weight and, similarly, they were filled with air. To prevent buckling and breakage they had struts of thin bone inside the cavities.

The flying apparatus consisted of a great web of skin (the patagium) that stretched from the fore limb to the hind limb and on to the tail. This web was attached to the body but its main support was one of the four fingers, which was enormously enlarged. The actual identification of this finger is not certain. By some authorities it is interpreted as the fifth or 'little' finger, by others it is regarded as the fourth. Either way, it is the outermost finger which is quite fantastically lengthened in all its segments to be the fore rim of the 'wing'. The remaining three fingers are all quite small and free. The skin of the web also extended for a small way between the neck and the other side of the fore arms.

All the Pterosaurs were tailed, but it is characteristic that many of the earlier, Jurassic, forms had long tails with a tail fin in some cases, whereas the later, Cretaceous, ones had short tails.

The hind legs were not strongly developed, indeed in some of the later examples they are quite feeble and the proportions of the different long bones vary in the different kinds. The four-toed foot is quite reptilian in character and all the toes usually have claws.

The principal characters of a few of the best-known flying reptiles may be briefly stated before we go on to discuss their habits and the problems associated with them.

The Lower Lias specimen from Lyme Regis is known as ***Dimorphodon*** on account of the two kinds of teeth in its jaws. The skull is large and light in structure and in the jaws there are large teeth in

front and small teeth behind. The hind legs are comparatively large and there is a long tail that is known to have been stiffened by ossified tendons.

Much better known is the little *Pterodactylus* ('wing-finger') whose name, at least the word Pterodactyl, is almost a common word. It is known by fine skeletons, beautifully preserved, from the Lithographic Stone of Bavaria. As the name of this deposit implies the stone is so fine grained that it was a valuable material in the older printing processes, and some of the fossils it contains have also preserved the imprint of the body, showing almost every external detail.

Specimens of *Pterodactylus* are also known, although only by fragments, from East Africa and England.

They are usually very small, about the size of a sparrow, although one or two of them grew as big as eagles. They are of Jurassic age, and their hind legs are still comparatively large, which is a primitive condition. A restoration of a typical Pterodactyl at rest is given in figure 64.

Rhamphorhynchus ('prow-beak') is another form well known from Lithographic Stone specimens and also by a few remains, thought to belong to it, from East Africa. It has a thin, pointed skull which is about eight inches long. It is one of the long-tailed forms and had a straight tail with a rhomboidal fin at the end (fig. 65). Its wing span, from tip to tip, was about thirty inches. The hind legs were still longish and its feet were webbed.

These are all Jurassic forms, but the reptilian monarchs of the air were in the late Cretaceous and are typified by the great *Pteranodon*. This name means 'wing without teeth' and implies that this flying reptile was toothless. The skull was not only toothless, it was extraordinary (fig. 66). It looks like a pair of scissors in which one handle has been lost, for the long bony jaws were counterbalanced behind by an equally long bony outgrowth.

The eyes were small compared with those of most of the Pterosaurs. The hind legs were small and could not have been used for walking, even if the wings had allowed that movement. But the wings were magnificent, great sails, as much as twenty feet from

Fig. 65 RHAMPHORHYNCHUS
A long-tailed pterodactyl. Two feet in length

wing tip to wing tip, and these reptiles were the albatrosses of the Cretaceous. The tail was a little stump, so that judging by the proportions of tail and limbs and the toothlessness, these were forms high in the scale of the evolution of the group. Indeed they were the last of it: the final attempt at complete mastery, and apparently an American attempt, for they are only known from that continent and from the Chalk of Kansas, although somewhat similar bones (not *Pteranodon*) have been found in the English Chalk. How then did these varied creatures live and move and obtain their food? We have described a little of their anatomy, what about the associated physiology?

It is significant that their remains have so far only been found in marine or estuarine sediments, that they have been buried at sea. In some cases we can actually calculate how far away the nearest land surface was at the time of their death. It is clear from this that they were often in the air far out to sea.

Their skeletons give clues as to their ability to cover these distances. There is evidence of sufficient strength of materials, but the lightness of the materials, associated with the flying function, is remarkable. Some of the bones are only one millimetre thick. A live pterodactyl of three feet wing span is estimated to have weighed half a pound! Some of the fossilized bones from the Chalk of England and Kansas even with the filling of matrix are astonishingly light.

Since the wing in structure, and especially in its support, was unlike the wing of a bird or of a bat, it is most improbable, indeed practically impossible, that the Pterosaurs flew in the bird sense. They were great gliders in which the expanse of the wing, the weight of the head, and the counterbalance of the tail all played great parts, subject to the comparatively high co-ordinative faculties of the brain.

The wing had some slight similarity with that of a bat for in some Pterosaurs there appear to have been elastic fibres in it.

The primitive tailed forms had the tail as stiff as a rod and the fin at the end of the long tail, in a form like *Rhamphorhynchus*, served exactly the same purpose as the tail plane of an aircraft; it kept the reptile from pitching. From this it would seem fairly

Fig. 66 PTERANODON
A reptilian forerunner of the albatross, with a wing span of eighteen feet

certain that when these forms turned they would do so almost on the flat and with very little banking, rather like a slow-flying training plane, though the animal had another control in its wings, as movement of the wing-finger joints would shorten and bend the wing membrane.

It is also probable that the smaller-tailed Pterodactyl types rested on trees by hanging upside down like a bat.

The almost tailless forms could bank as they wished, as they could make more skilful use of the air currents. Banking turns would enable *Pteranodon* to look around carefully and, then, having seen its prey, it could use its weight (in a relative sense) for a speed dive, a swoop over the crests of the waves (like the albatross) and the capture of its prey.

All of these reptiles seem to have lived on insects or fish, and some of them had a pouch in the throat like a pelican. Presumably they launched themselves from a cliff and, using the wind, glided in search of their food. If it was calm they would have to use the greatest skill to avoid being becalmed themselves. On the other hand, if it was rough, the greatest care must have been exercised to see that the fragile wing tips were not fractured or the wing torn. It is thus perhaps difficult to imagine their complete flight from shore to shore again. The large forms appear to have rested on the hind limbs with the wings folded up (like an unrolled umbrella) at the sides.

There is another problem too, the physiological one. Reptilian metabolism seems far too low for flight even of this nature, and since these creatures had their bodies and their feet frequently off the reptilian ground, it is just possible that they were warm-blooded to some degree. This is not quite so fantastic as it may seem and it may be said that one of the finely preserved Jurassic Pterosaurs from Germany has actually got hairs in its skin! When reptiles develop warm blood and hairs, it is perhaps time to leave them, but not before we reflect that the reptilian essay at flight lasted, apparently successfully, for over fifty million years, and was only beaten by the impenetrable barrier, for them, of the Mesozoic-Cainozoic junction.

CHAPTER XV

THE BIRDS TAKE WING

TRUE birds, that is animals capable of flight by the motion of their paired wings, and whose wings were composed of, and whose body was covered with, feathers, first appeared in the Jurassic and the first remains that we know come from the celebrated Lithographic Stone of Bavaria, from which so many fine examples of flying reptiles have also been obtained.

In addition to this one common site the birds and the flying reptiles have several features that are alike. For instance, the skull is largish but light in construction and its bones are closely fused together. Both groups have hollow bones and, correlated with the strong muscular development of the arms, they have a well-developed breastbone.

The birds have, however, strong hind limbs as a rule, while as we have seen, the most advanced Pterosaurs had only feeble legs. In the case of the birds this seems to imply retention of the original walking use of the limbs, whereas in the Pterosaurs this function had been allowed to lapse and was never regained.

Given such similarity there has naturally arisen the question as to whether the birds are descended from the flying reptiles. There are several differences in the hands and feet that argue a different ancestral habit and as the birds, fully fledged, appear in the geological record only very slightly later than the Pterosaurs it is clear that they are not directly descended from the flying reptiles. It is, however, fairly certain that both were derived with the dinosaurs, from a Thecodont ancestor.

We have already seen that there were osteological similarities in the pelvis and the feet between dinosaurs and birds. These are more apparent than real, for in the case of the pelvis it is argued that the dinosaur bird-like pubis and the bird pubis are not the same thing at all, and the form of the feet is due to the same bipedal mode of progression which inevitably, in forms running on their toes,

Fig. 67 ARCHAEOPTERYX
The earliest known bird was about the size of a crow

throws most of the weight on the middle toe and causes a re-orientation of the arrangement of the other toes.

There has been a good deal of speculation and controversy about the origin of the birds from a reptile and the theory that seems most acceptable nowadays is as follows.

Some of the pre-dinosaurian Thecodonts were small lizard-like animals with long tails. When we wrote of them (p. 136) it was already suggested they could run on their hind legs. Some such forms may have so developed both the bipedal and the running habit with the result that the middle toe (third digit) was becoming prominent compared with the others. One or two of these types of animals became arboreal, just as at least one early Ornithopodous dinosaur became partly arboreal (*Hypsilophodon*). In the case of the former they became progressively more and more adapted to life in the trees and also adopted the habit, observable in modern lizards and even in snakes, of leaping or even falling from tree to tree or from tree to the ground.

Two anatomical results of such climbing and leaping are possible

and even likely. Firstly, that the hands and feet would become specialized for grasping. This would be most noticeable in the end phalanges (the finger tips). Secondly, the use and corresponding strengthening of the muscles of the upper arms and chest would help to cause the two front halves of the chest bones to unite and eventually to form a strong breastbone. As we have already seen this happened for another reason in the Pterosaurs.

Long continued practice of the jump or glide from tree to tree would probably tend to produce a ridge of scales along the hinder (leeward) side of the forearms and along the sides of the tail, which would tend to become flattened, above and below, and which as a balance would be carried stiff and pointed straight backwards. A flap of skin is known to be developed along the side of the body and behind the arms in some modern arboreal lizards.

In the course of time, and they had a few million years at their disposal, these arboreal reptiles persisted in these habits of living in the trees, where they would find plant food, or of leaping through the air to catch insects. As this practice went on the scales on the arms and the tail became frayed, not just in wear and tear, but as a response to continued friction by the air. This development eventually went so far that no longer were scales grown on these parts of the body but instead there were modified scales which we now call feathers.

Thus the arm with its backwardly directed feathers became a primitive wing and the tail, with its feathers directed backwards and outwards, became a bird-like tail.

With such an external (dermal) organization it is most unlikely that the body would have feathers restricted to the arms and the tail and reptilian scales elsewhere. Once the development of feathers had started they would eventually be grown all over the body except on the constantly eroded surfaces of the hands and feet, and so a feathered reptile would come into being, which is certainly just as feasible as a hairy reptile of which there seems to be evidence.

This reptile, with its feathered 'wing', had no great skin patagium like the Pterosaurs. Its flight was for long probably a gliding one,

but it is certain that flapping of the arms for extra effort would be tried and eventually would be commonly used.

Since these reptiles were arboreal, they were already partly protected from the fierce heat of the sun by day and from the cold of the ground at night. The physiological requirements of flight would be greatly increased metabolism, quicker breathing and so increased blood circulation. The quicker breathing affected the limb bones; the light hollow bones developed long before were filled with air, as in the Pterosaurs, but air-sacs were developed in the body too and the lungs inevitably enlarged. The heat engendered by increased circulation of the blood was not readily lost for the feathery covering acted as an insulator and the development of a permanently warm-blooded condition was thus assured.

Such modifications, associated with the keen sense of sight that was present in the Pterosaurs and with the need for an acute sense of balance and control of the musculature used to ensure this, would result in a general refinement of the brain. This last factor was, and is, immensely important. In the human race two diverse groups, airmen and organists, share the need for visual acuteness, that is a high degree of perceptiveness, and muscular co-ordination. For the organist they decide whether he will be a good or bad executant, but for the airman they mean life or death.

The first bird was fighting for its life and in consequence of this, given its new and remarkable advantages, it produced a new stage in the development of the brain.

This, of course, is largely conjecture, but at least, plausible conjecture. If it is true, where are the remains of the many early Jurassic developing forms? For that matter, where are the trees upon which they climbed, leaped and slept? As they were living on the high and dry ground there would be little opportunity for their remains to be preserved long enough after death for fossilization. Any skeletons that might be preserved under these circumstances would not show the peculiar dermal outgrowths.

It was not until the bird-reptile had attained the power of flight to a considerable degree, until it was being 'produced' in moderate numbers, that one or two of them were brought down in the quiet

Fig. 68 ICHTHYORNIS

A toothed flying bird about the size of a pigeon. From the Cretaceous of Kansas, U.S.A.

waters of a German lake. Here conditions were suitable for preservation to a fine degree. So in the Lithographic Stone of Bavaria we have one or two specimens of the bird of this conjecture, preserved not only as skeletons but with the outline of the wings and feathers beautifully preserved upon the fine stone. These are the first birds that are known, the 'ancient wings' or *Archaeopteryx*.

Only three specimens are known, a good skeleton with the skull that is still preserved in Berlin, a less satisfactory skeleton (about

two feet long) with only parts of the skull but with a cast of the brain and good impressions of the wings and tail, preserved in London, and a feather once on exhibition in Munich, but now perhaps destroyed.

The skeletons reveal several reptilian features that one would expect from the ancestry outlined above. Although all modern birds are toothless, these fossils have true teeth in their jaws. The vertebrae are quite reptilian and have flat, or very slightly cup-shaped articular ends. The wing has three fingers with large curved claws, of which the middle one is much larger than the other two. Only the tips of the fingers and the claws would project beyond the feathery upper surface of the wing. The foot is four-toed and quite bird-like with the first toe shortened and spur-like at the back.

The tail is reptilian in underlying structure for it consists of twenty vertebrae, each having a pair of feathers. Hence the tail was long and not a short bunch of feathers as in modern birds.

The London specimen shows a complete 'merrythought', the forked bone in the breast.

Naturally these specimens have been studied by many specialists, and it is now thought that the specimens may belong to different genera; the London specimen is still called *Archaeopteryx* but the Berlin one is renamed *Archaeornis*. None the less, they must have led very similar lives and Gerhard Heilmann in the *Origin of Birds* has painted a very lively picture of these early days. It is true that perched upon a frond of a tree-fern, these primitive birds must have been a little grotesque, for the purely reptilian head, without a beak and with the toothed jaws, would convey the impression of a reptilian masquerader rather hopefully attempting to deceive the world with a new and gaudy tippet of feathers around him (figs. 6 and 67).

They were, however, real flying birds, probably as yet a little awkward, and in some ways not quite so much at home as the dragon-flies or even as some of the Pterosaurs. With what colours they decked themselves we cannot say; in what tones of voice they called to one another we do not know; how long even the group survived we cannot estimate; for had these two or three examples

not been preserved by very favourable chance in the remarkably suitable fine limy mud of a Jurassic sea, we would have known nothing at all about them and the long story of the origin of birds would be wholly conjectural.

The next recorded steps in avian progress are from the Cretaceous, from the Chalk of Kansas, U.S.A. They are represented by two kinds of birds, still toothed, but of different habits.

Already it can be seen from such examples that the birds were well established and well on the way to becoming the kinds of birds with which we are familiar today. Already also, one of them had given up the struggle in the air and had returned to the water. This was *Hesperornis* (the 'western-bird'), which is shown in fig. 69, a swimming-bird closely similar in habits to the modern divers or loons. From this point of view there is nothing very remarkable about it except that it had already lost its flying powers and was adapted for hunting the abundant prey in the waters and that it had a peculiar arrangement of teeth. The skull was long and narrow; the lower jaws had teeth along a groove in the jaw margin, but the upper jaw was only toothed in the hinder half, and the front upper jaw was presumably cased in a beak of some sort.

Hesperornis was about four feet high.

Living at the same time there was a smaller bird, *Ichthyornis* ('fish-bird') which was only nine inches high (fig. 68). It had toothed jaws on exactly the same plan as *Hesperornis*, but in this case the teeth were in separate sockets. The vertebrae of the backbone are, in some cases, biconcave at their articular ends and this is a retention of a primitive condition.

Ichthyornis was a flying bird of some ability, for the breastbone is strongly keeled, and it was no doubt a fish-catcher. Both of these birds were buried at sea and then preserved in the oozes that subsequently built up the Chalk of Kansas.

At the end of the Cretaceous period, when conditions were such that the great reptiles died out, whether Dinosaurs, Ichthyosaurs, Plesiosaurs or Pterosaurs, the birds were able to continue. From then onwards their development was always towards the existing forms.

There is evidence that at one time there were in the southern

hemisphere more ostrich-like flightless running birds, such as the Moa, than there are today and some of them attained a great size. One of them, *Dinornis*, for example, was nearly nine feet high. They were especially common in New Zealand where they were hunted and eventually exterminated by the Maoris.

In many ways the birds appear to be one of the most successful forms of life. Having mastered the air, many of them are at home on the sea as well as on the land, and it is difficult to imagine conditions, apart from a generalized and severe fall in temperature, that will stem their slow but sure advance.

The freer the choice of habitat, the greater the chance of survival. So the birds lived on while the massive, highly adapted and correspondingly over-specialized reptiles died out as the days of the Cretaceous dimmed and the more modern Cainozoic Era appeared.

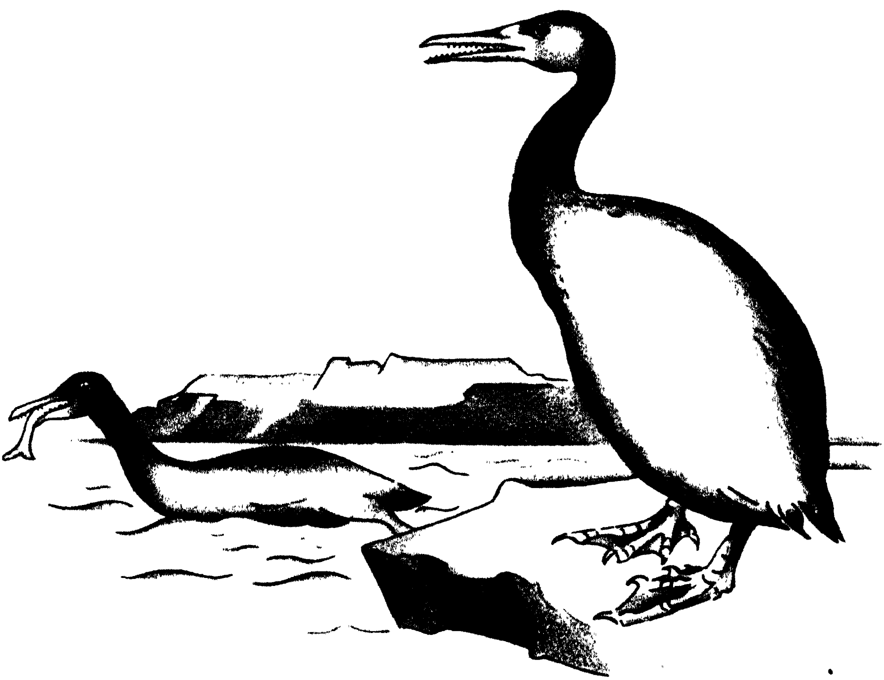


Fig. 69 HESPERORNIS
A toothed flightless bird from the Cretaceous of Kansas, U.S.A.
The bird was about four feet in height

CHAPTER XVI

THE COMING OF THE MAMMALS

When the new age that we call the Cainozoic ('new life') dawned the dominant reptiles had gone. They left the comparatively insignificant forms whose descendants are the reptiles now existing; and the little mammals, hitherto unnoticed hairy occupants of the bushes and the undergrowth, seized their chance and in a very short time took the place of the large reptiles. Indeed, if intent could be ascribed to them, it might be said that they endeavoured to repeat the reptilian performance, for in the earliest Cainozoic [i.e. the Eocene (Greek: *eos*, dawn; *kainos*, new)] period, there were large horned and grotesque mammals that were, in some ways, as specialized and as abortive as the great terrestrial reptiles.

With these forms we shall have to deal later. Between them and the progenitor of the mammals there was, however, a gap in time of nearly one hundred and twenty million years.

It is necessary, therefore, to pause for a moment or two to consider this gap and what was going on between the birth of the first simple reptile-like mammal, which occurred in the Trias of South Africa, and the advent of these Eocene forms that were beginning literally 'to throw their weight about'.

We know that the first truly mammalian forms were very similar to the mammal-like reptiles, and yet the latter, as far as their skeletons are concerned, are clearly distinct. Among several distinguishing features perhaps the most important are the structure of the lower jaw and the nature of its hinge with the skull.

What is a mammal and what, in brief, are its distinguishing skeletal signs?

The definition of a mammal is, an animal that suckles its young. However admirable or demonstrable this definition may be for zoologists, it is obviously not much help to the palaeontologist. The skeleton does, none the less, help in identification.

The skull in mammals is more compact and the number of bones is fewer. There is never a pineal foramen. The occipital condyle is bifid, or has two articular surfaces like an amphibian (hence it was held for a time that mammals were derived from the amphibia). The mammalian lower jaw is composed of only one bone and it articulates with the squamosal bone of the skull; there are resultant changes in the ear region. Mammalian teeth are differentiated into incisors (front cutting teeth), canines (dog or eye teeth), premolars and molars, and there are normally only two sets, a so-called milk series and a permanent series. Some mammals are, of course, toothless (e.g. adult monotremes, some ant-eaters and some whales). Nearly all mammals have seven vertebrae in the neck, however long that neck may be, but there are exceptions to this rule in the sloths.

The shoulder and hip girdle too show a reduction in the number

Fig. 70 ARSINOITHERIUM
A large Oligocene mammal from Egypt. It measured about twelve feet in length

of bones through fusion. The number of digits in the feet is typically five, but there are well-known exceptions to this (e.g. the horse), and the number of phalanges (joints) in this arrangement is usually 2. 3. 3. 3. 3; the thumb or great toe having two and the others three, but there are also exceptions to this.

These features are largely culled from an examination of living forms, for it is regrettable that throughout the long historical period of their development the mammals have left few traces, and skull features are perhaps better known than those of other parts of the skeleton. Skull fragments are more interesting, and teeth are more important, and more easily determinable, than isolated parts of a skeleton.

We have already seen in Chapter XI that some Theriodont reptiles, notably one called *Ictidosaurus*, approached the mammalian skull plan so closely and already had such differentiated teeth, that but for its retention of the reptilian jaw-hinge, we should call it a mammal.

Another form, *Tritylodon* ('three-knot-tooth') from the Trias of Basutoland, South Africa, with molar teeth divided into three knots or nodes, was described by Sir Richard Owen as a mammal and was long thought to be one. It was known for many years only by a part of a skull with the upper rows of teeth.

During recent years remarkable finds of animals closely related to, and belonging to the same family as, *Tritylodon* have been made in places as far apart as South Africa, China and Oxfordshire. These show close similarities in the teeth, their roots, the skull and the size of the brain, and also close resemblances in the limb bones to those of true mammals, yet the articulation of the jaws is truly reptilian. So the Tritylodons, for all their similarities, are reptiles. Since even in our English countryside they were Triassic contemporaries of true mammals with a different tooth pattern, they cannot be the ancestral forms.

The nearest ancestral reptile is still a missing link, although we know fairly accurately what features it must have had. The mammalian evolution probably took place in the late Trias in South Africa, but it is clear that the new forms must have moved quickly

for in the uppermost Trias mammals had already arrived in Southern England and by the middle of the Jurassic they were in Mongolia and America.

In order to understand these forms it is necessary to refer briefly to the main classification of the mammals as we know them today. The lowest forms of mammalian life now existing are restricted to two genera of a peculiar kind known together as the Monotremes. These are small, burrowing animals found in Australia, New Guinea and Tasmania today, but obviously the survivors of an ancient and degenerating race. They are unique among mammals in that they lay eggs. Their skeletons still retain reptilian features in the girdles and limbs. The adults are toothless but the young animals have teeth.

The two surviving genera are *Ornithorhynchus*, the Duck-bill Platypus, and *Echidna*, the Spiny Ant-eater. The Duck-bill is about eighteen inches long, has a soft-furred body and a short, broad tail, and has a flattened bill like a duck's with which it burrows in the mud after the worms and insects on which it lives and which it crushes with its hardened, plate-like gums. It has webbed feet and lives in the water. Its small eggs are laid in a nest on land and hatched by the mother, who also supplies the new-born young with milk.

The jaws of the young duck-bills have several teeth which are covered by rows of small tubercles and are thus very similar to the teeth of some of the oldest-known mammals, called, as we shall see, the Multituberculates.

Spiny Ant-eaters have a long snout and snare ants and other insects with the tongue, which has sticky saliva. The body in these animals is covered with stiff spines. The eggs are carried in a pouch of skin on the abdomen.

The next class of lower mammals contains the Marsupials, again the restricted remnants of a formerly far more extensive group. Today they are found only in Australia, Tasmania and adjacent islands, and in America (the opossum). They are much more familiar to the public than the Monotremes, since they include the kangaroos, etc.

The young are born, not in eggs, but as very small living creatures which are transferred by the lips of the mother into a pouch (marsupium) on the abdomen. This pouch is supported by two special bones, really ossified tendons, that are not known in higher mammals but occur in the Monotremes, the Crocodiles and in Newts.

The marsupials have teeth which vary in character and number and are much used by zoologists in classification.

The next group of the mammals is an enormous one, the Eutheria or true mammals, and it includes most of the animals that are familiar to us as pets, as the source of our food, or even as enemies. It also includes Man.

Fig. 71 UINTATHERIUM
A grotesque form from the Eocene of America. It was about twelve feet long and six feet in height

Now this last group is obviously so advanced that it is of no use for our present purpose of tracing mammalian ancestry.

The palaeontologist is therefore faced, like the builder of great bridges, with one solid pier of information, the first fossil mammals, on one side and on the other the primitive Monotremes and Marsupials. His task is to build forward from the one side and backwards from the other, till the historical pathway is complete. And it is not easy. The actual gulf comprises the Mesozoic, that age of dominant reptiles which nevertheless contained mammals whose affinities are doubtful. Their scattered remains, found in Europe, America and Mongolia have, fortunately, been exhaustively studied in recent years by one or two brilliant anatomists and something definite appears to be deducible from them now.

When we started this chapter we referred to the reptile-mammal known as *Tritylodon*, which is now known to be a reptile, and attention was drawn to its tuberculate teeth. A group of Jurassic mammals is known to have very similar teeth, and these have come to be called the Multituberculates. They include *Plagiaulax* and *Ctenacodon*, which are known from the Jurassic of Europe and America, but the order survived, in *Taeniolabis* and others, into the very beginning of the new Cainozoic era of North America, Europe and Asia.

We have just pointed out that the teeth of the young Duck-billed Platypus are also multituberculate, and so it is natural that there has been a tendency, perhaps rather a desire, to link the Mesozoic Multituberculates with the Monotremes.

The former were all small animals, mostly like mice in appearance, though some grew as large as a beaver, but they all show highly specialized teeth, some adapted for a vegetarian and others for an insectivorous diet. In some ways their teeth suggest an affinity with the Marsupials, but there is a good deal of evidence to suggest that this was an old and specialized race that merely died out in the Eocene and was not the ancestor of Monotremes or Marsupials.

Another interesting group of Jurassic mammals was that of the little rat-like Triconodonts known from England and America. *Triconodon* itself comes from the Purbeck Beds (uppermost Jurassic)

of Swanage, but a more important genus is *Phascolotherium* from the Stonesfield Slate, in which several remains have been found. This group did not survive into the early Cretaceous but became extinct and appears to have left no descendants.

The third group of Jurassic mammals that we will deal with here is known as the Pantotheria, though sometimes they are called the Trituberculates.

In England they are represented in the Stonesfield and the Purbeck Beds already referred to and they also occur in Wyoming and Colorado in the United States. They are typically represented by the small *Amphitherium* which was an insectivore. Some of these animals have a dental arrangement which makes possible the derivation from them of both the Monotremes and the Marsupials. This is at least an advance on the other theories. The possibility is heightened by the discovery of primitive, but true, insectivores in the Cretaceous of Mongolia that would seem to link these earlier Jurassic trituberculates with the true mammals. Unfortunately the ancestry of the trituberculates themselves is not clear.

This suggestion would imply a swift mammalian spread over the continents, as we have said earlier, for the origin of the mammals from a Theriodont apparently took place in the Trias in South Africa; the trituberculates were already spread from Europe to

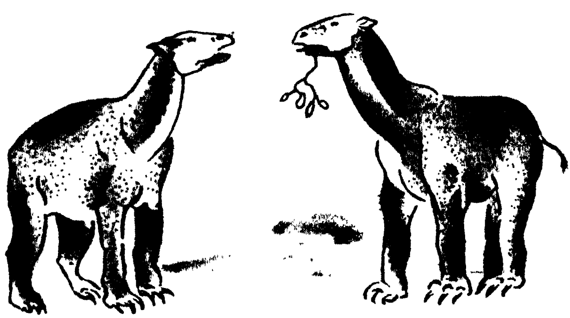


Fig. 72 MOROPUS
A clawed ungulate, numbers of whose skeletons have been obtained from a quarry in Nebraska, U.S.A. Seven feet long

America in the middle of the Jurassic; in the Cretaceous of America there were developed the opossums which are marsupials; and in the Cretaceous in Mongolia there were arising rat-like insectivores, the small furry and whiskered progenitors of most of the mammals of today. Thus quickly and by the end of the Cretaceous the mammals were all set for expansion.

Other things were happening in the Cretaceous too. The sombre evergreen vegetation was being reinforced by trees that shed their leaves. The flowering bushes and plants were adding colour to a hitherto dreary flora. Coincidentally there were the bees and the wasps to add their humming to the squeaking of the mammals; these were new noises where for centuries the roar of reptiles had been heard.

From the leafy branches the birds were rehearsing their songs for the new days that were shortly to dawn.

The changes in the vegetation were symptomatic of greater geographical changes that were taking place. The lands were uprising and new mountains were rearing their heads; the seas were altering their shapes, and the uplift of continents drained vast areas of land. Within the seas great new deposits were being laid down and the very currents changed their courses. As the face of the earth changed, the climate altered also.

The homes of the dinosaurs and the other great reptiles were being altered or destroyed, their food supply was diminishing. When the Cainozoic Era was ushered in with the Eocene it is not surprising that they were not there to greet it. The mammals therefore were able to step into their place and in the following pages we can describe only a few of the more interesting and well-known forms that lived during the sixty million years or so that have since elapsed.

Already in the Eocene the mammals had grown out of all recognition; from small and scuttling creatures of the undergrowth some had become almost as large and grotesque as the dinosaurs.

One such form is *Uintatherium* (the Uinta beast), whose remains are well known from deposits at the Uinta Mountains of NE. Utah.

It is sometimes called *Tinoceras* ('stretched horn') and also *Dinoceras* ('huge horn'). A related form is *Eobasileus* ('dawn king'). A reconstruction of *Uintatherium* is shown in fig. 71.

These form a separate Order, the Dinocerata. Hoofed animals of the Orders existing today, the Perissodactyla, or odd-toed animals, such as a horse, and the Artiodactyla, such as the cow, were represented by small beasts about the size of a fox-terrier. The Order Proboscidea, to which elephants belong, alone contained larger animals, up to three feet high at the shoulder.

The hoofed mammals were originally small vegetarians which lived in the forest glades or near the marshlands for which their five-toed feet were suitable, but whereas the modern ungulates have advanced in size and in the adaptation of both feet and teeth, the Eocene group that produced *Uintatherium* and its relations simply advanced in size. They grew in stature to something between a rhinoceros and an elephant and their stumpy feet have earned for the group to which they belong the name of Amblypoda ('blunt feet'). Their limbs were very massive to support the overgrown body. As if this was not enough the skull developed great knobs of bone or horns (fig. 71). *Uintatherium* has three pairs of these which increase in size from the snout to the back of the skull. These horns were covered with skin during life, but they are of solid bone, like most of the braincase.

Casts of the braincase have been taken and the brain was small compared to the size of the skull; indeed, *Uintatherium* had a brain the size of a dog's, or half the size of the brain of a hippopotamus, whose body size it exceeded. The sense of smell was apparently very well developed.

These Eocene herbivores seem to be mammalian counterparts of the Cretaceous Ceratopsian dinosaurs. The teeth are adapted for grinding succulent vegetation, but in the late forms the canine teeth in the upper jaw were enlarged to form a pair of downward-pointing tusks which were partly protected from breakage by specially developed flanges of the lower jaw.

In the Upper Eocene, Dinocerata reached their maximum and final development as is shown by *Eobasileus* which had a very long

skull and large canine tusks in the male while the female had smaller horns and tusks.

These large and bizarre animals quickly attained their maximum and then became extinct. They are interesting diversions but they contributed no descendants to the main evolutionary line.

A somewhat similar development in another Order, the Embrithopoda is seen in *Arsinoitherium* from a later deposit, the Lower Oligocene of the Fayum, Egypt. The name is derived from Arsinoë, an ancient Egyptian town, and the Greek word *therium* meaning beast, and thus conveys some hint as to its place of origin but nothing of its nature. This was another large animal with a skeleton twelve feet long (see fig. 70). It was rhinocerine in appearance and there is little doubt that it was the largest mammal of its time.

It was nearly six feet high at the top of its shoulders and the great body was supported on stout legs with, again, stumpy five-toed feet. The feet were suited for a grazing habit, which is also borne out by the teeth which are adapted for grinding dry vegetation. The incisors here are small and not specially developed in any way.

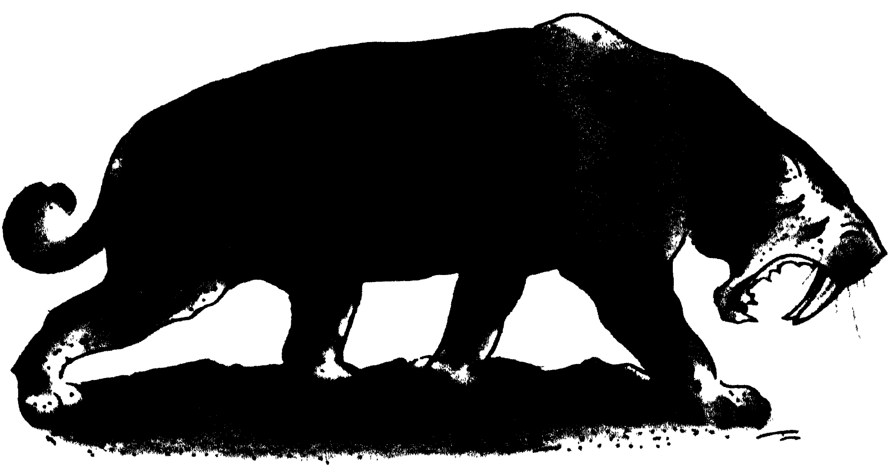


Fig. 73 MACHAERODUS
The sabre-toothed tiger, whose remains are found in the Pleistocene of Europe

Towards the back of the skull roof are two small horn-cores but they are connected towards the front with two great bony horns, two feet or more in length, which were covered in life with a horny sheath. These horn-cores were hollow.

The brain of this animal was larger than that of the Amblypods, so that it was probably a formidable creature for these times.

Its precise relationships are obscure, but it is clear that it was not an ancestor, even if it was a precursor, of the rhinoceroses. It may, however, stand somewhere near the line of descent of the little existing hyraxes of Africa and Arabia.

Animals related to the rhinoceroses were living in America during this period and in many ways these also resemble, in bulk and boniness, the Uintatheres and the Arsinoitheres. They are known as the Titanotheres. Like *Uintatherium* they had horns on the nose, like *Arsinoitherium* the teeth were in a continuous series, but they had only four toes on the front feet and three on the hind feet. The last of them were all fairly large beasts, fifteen to eighteen feet in length.

The later development of all the members of the ungulates cannot be dealt with here even briefly, since it is a subject that would require a large volume to itself, but the so-called evolutionary series of the horses and the elephants are dealt with in the next chapter.

Of many of the others, such as pigs, deer, giraffes, etc., peculiar and aberrant forms, some of which were presumably large, were developed in the Tertiary. The short-necked giraffe, *Sivatherium*, is well known.

Attention may be drawn to a Pliocene ruminant with remarkable horns, *Synthetoceras*. This will be referred to for other reasons in the next chapter (fig. 83).

During later times in the Miocene and the Pliocene, there were living in Europe, America and Asia, a peculiar group of ungulates that had teeth like the Titanotheres mentioned above, but which had feet quite different from other ungulates. They had three-toed feet but the toes had claws that could be drawn in like those of a cat. One of these animals was *Moropus* ('stupid foot'), many skeletons

of which have been excavated in America. This peculiar ungulate (fig. 72) used these claws for both digging and scooping, as picks and scrapers. The feet are remarkably like those of the extinct ground sloths of America, and when first they were found they were thought to be from a ground sloth.

The ground sloths are not ungulates but belong to the Edentates, the group that contains the ant-eaters and the sloths that we know today. The ground sloths are known from the Miocene onwards, but it was in the latest periods of the Tertiary that they attained their maximum and they then existed in great numbers and were contemporaries of Man. There is, in fact, some evidence that some were kept in captivity by early men in South America.

Large, hairy, cumbrous creatures, they combined in their skeletons some of the characters of the ant-eaters with the skull and teeth of a sloth. From the great size, nearly twenty feet long, it is obvious that they could not live in the trees as do existing sloths, but the details of their skeletons give clear indications as to their habits. The stout hind limbs and the tail formed a base for the animal to assume an upright position and the bones of the pelvis are so formed that they are a kind of tray to hold up the weight of the viscera. That they were strong and muscular is evident from the markings of the muscles upon the bones.

The feet were twisted so much that their sides would be used in walking. Some of the toes had great digging claws, and the front feet were eminently suited for grasping.

The front of the jaws formed a scoop and the four teeth on each half of the jaws were adapted for grinding. It is therefore easy to picture them in life (fig. 79) squatting upon their substantial hind-quarters and tearing off the leaves. Yet, though their excrement is known, it consists only of the remains of grass and no leaves have been found in it, so that they must have done a good deal of grazing as well.

Their remains are especially well known from the Argentine where it is certain that they were hunted by men, and where stone implements and human remains have been found in close association with them.

Men were not their only enemies, for at that time there were fierce carnivores that preyed upon the browsing and grazing herbivores.

These carnivores had a history dating from the Miocene and they were all cats. Among them were the ancestors of the true lions, tigers and cats of the present day, but there were also the Machaerodonts, the so-called sabre-toothed tigers. These last were not true tigers in the zoological sense, but the name has been given to them on account of the extraordinary canine teeth of the upper jaws, which

Fig. 74 MACHAERODUS ATTACKING A GROUND SLOTH

were sharp, recurved, compressed from side to side and nearly seven inches long (fig. 75).

There was an arrangement of the jaws whereby the lower one could be pulled backwards and downwards to open the mouth for the effective use of these cruel fangs. As these animals were often as large as lions, it needs few words to convey the terror they must have struck upon their fellow creatures. *Machaerodus* (figs. 73 and 74) is known from the Miocene to the Pleistocene in Europe and the similar *Smilodon* from the Pleistocene of North and South America.

Fig. 75 SKULL OF THE AMERICAN SABRE-TOOTH, SMILODON, SHOWING THE MOVEMENT OF THE LOWER JAW
Hundreds of these skulls have been found in asphalt beds in California

Apart from the comparatively small and unobtrusive forms that were to develop into the fauna that we know today, we see among the mammals those same developments of cumbrous size, of horn, of teeth and claw that we saw among the reptiles. Even the humble marsupials produced a monster in *Diprotodon* (fig. 84).

Like the mighty dinosaurs, all these great creatures, Uintatheres, Arsinoitheres, Titanotheres, the great sloths and the cruel and terrible Machaerodonts, had their day and faded away from the history of life. None of them left a descendant.

What fate determines these mighty growths and, at the same time, seals their doom? In so far as we can answer that question we shall do so in the next and final chapter.

CHAPTER XVII

EVOLUTION AND EXTINCTION

THE previous chapters have been a series of descriptions of the life of various groups of animals during progressive periods of the geological record. The result is only a sketch, for even a brief reference to all the forms of life that we know as fossils would require a ponderous volume.

Yet even this brief survey is sufficient to emphasize several underlying problems; problems that for a hundred years or more have caused men to philosophize or merely to wonder; problems that are still unsettled even today, when we have a far greater range of facts at our disposal.

Life as seen in the geological record appears to consist of a large number of forms becoming progressively larger or more specialized or moving to some other kind of habitat or, more rarely, remaining small and comparatively undifferentiated. To unravel the implied relationships is the greatest problem.

More than a hundred years ago the variety of animal and plant life caused little difficulty. The doctrine of special creation existed and this made necessary only the description of the facts of size and of form, and perhaps the similarity to other kinds of life.

But men will not leave well alone. Just as the invention of the microscope altered all conceptions of living matter and revealed smaller and smaller basal units of living structures, so the gradual accumulation of fossils brought more and more closely together the remains of things that were suspiciously alike.

Does this similarity imply a movement from one form to another? Do little animals become in the course of time and generations other larger animals with different habits? Many men saw in this the same process, though in a different medium, as the development of land forms, the change of geographical features, by the works of rivers and the sea; that is, a process of unrolling, of development, that was known as evolution.

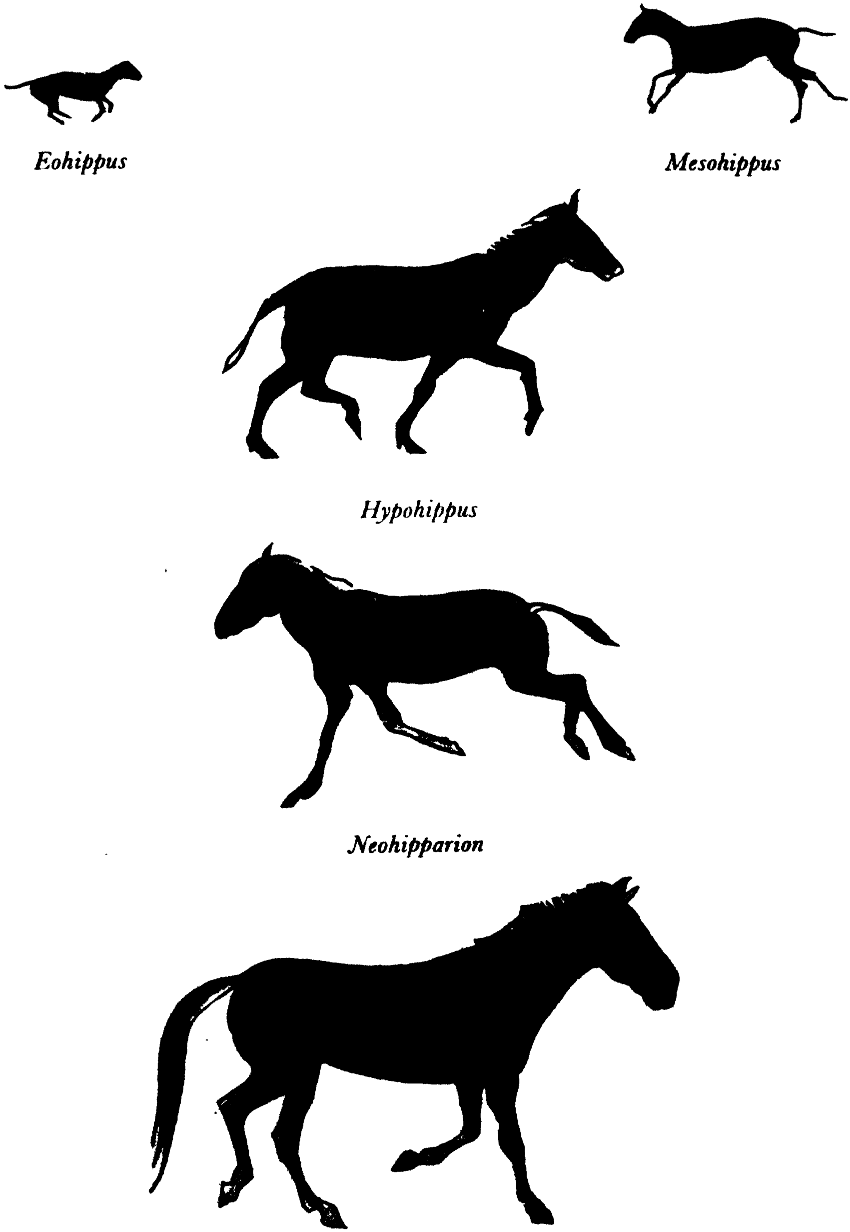
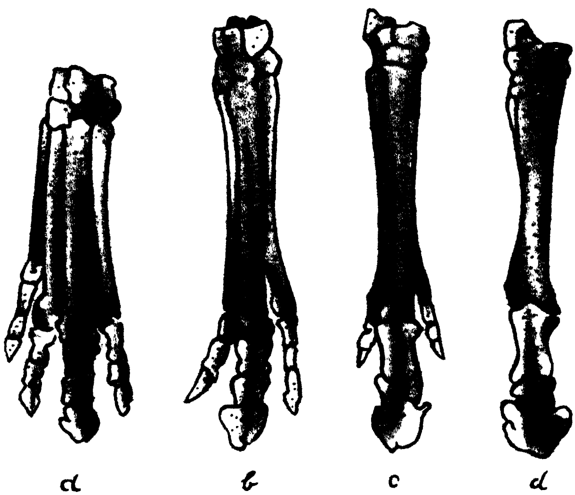


Fig. 76 THE RISE OF THE HORSE

Evolution to many people is something that Darwin said about men and monkeys. But the term was used before Charles Darwin wrote his *Origin of Species By Means Of Natural Selection* in 1859.

Cuvier, the great French anatomist, to whom we have already referred, might well have been one of the 'evolutionary' pioneers, but he stuck to his comparative anatomy.

His countryman Lamarck, however, was bold enough to put forward the theory that the changes in the development in series of animals were responses to the environment. Life was a battle between the organism and changes in its food, geographical and climatic environments; to become successful the animal might, for example, have to alter the pattern of its teeth, grow larger legs, or increase the size of its neck.



Evolution of the Hoof.

a. Four-toed front hoof of Eohippus.
b. Miohippus, minus fourth toe.
c. Merychippus, rising on tip-toe.
d. The modern hoof.

Fig. 77 THE DISAPPEARANCE OF THE HORSE'S TOES

Darwin suggested that this was not so, but that if in any group with various kinds of teeth, legs or necks, some were more obviously adapted to the habitat, then by natural selection these would live on and transmit their qualities to their young, while those with less efficient adaptations would die out. In this way, as time went on and 'evolution' worked, diverse kinds of highly specialized animals might be produced from a single ancestral group by the process of selection.

Both of these ideas have their supporters and, of course, their critics, but the supporters of Darwin far outnumber those of Lamarck.

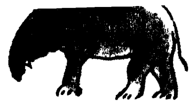
Concerning many of the fossils that we have mentioned, the phrases, 'derived from', 'gave rise to', 'were evolved' have often been used and it might well be expected that, in the great series of fossils that we now know from actual specimens, some clear lineage should be observable.

This is not strictly correct. We know only a few lineages over any great length of time. The best-known and most popular so-called evolutionary series are those of the horse, the elephant and the titanotheres.

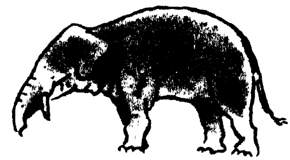
The evolution of the horse is shown in the usual manner in figs. 76 and 77.

The series no doubt started in the Cretaceous with a small five-toed animal, but in the Lower Eocene of North America there was *Eohippus* ('dawn horse'), which had four toes in the fore feet and three in the hind. It was a little whippet-like animal, only eleven inches high at the shoulder. It should be noted that its legs were comparatively long. It had simple grinding teeth for browsing on the succulent vegetation of the period. It was quite unlike a horse and would hardly be accepted as a relative were not the intervening stages between it and the modern horse well substantiated.

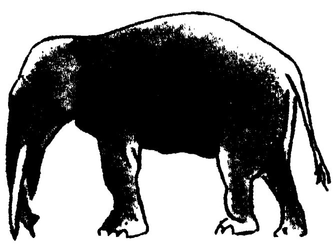
In the next period, the Lower Oligocene in America, there is *Mesohippus* ('middle horse'). This member of the family was larger, up to eighteen inches tall, and was well built for speed. Its adaptation for speed is seen in that the fore foot, as well as the hind, had now only three effective toes. The middle, or third digit, was



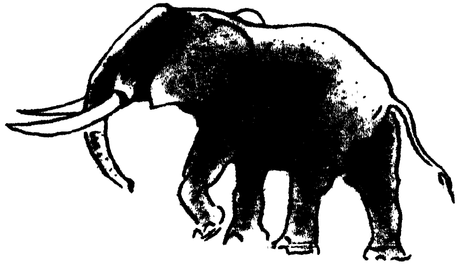
MOERITHERIUM



PALAEOMASTODON



TETRABELODON



ELEPHAS AFRICANUS

Fig. 78 THE GROWTH OF THE ELEPHANT AND HIS TRUNK

larger than the other two, the second and fourth digits. Towards the end of the Oligocene there appeared *Miohippus*. It was also three-toed, but the side toes were of still smaller size.

The Miocene horses, including *Merychippus* and *Hypohippus*, were still larger, indeed the latter was the size of a pony. They were becoming adapted for grazing, and the feet with the much shorter side toes were suited for soft ground. *Merychippus* was in the direct line but *Hypohippus* became extinct in the Pliocene.

Pliohippus of the Pliocene attained the one-toe standard, but probably the side toes were still retained though useless, and by Upper Pliocene time the series is represented by *Plesippus* which was practically the same animal as the Pleistocene and modern horse, *Equus*, which has only one functional toe and in which the outer toes are represented merely by the 'splint bones'.

The fossil horses are found widely in America, Europe and Africa and there are many side branches. Most of the tables and figures showing them are not true genealogical tables, for the gradations must have been very fine, and even in North America, where the evolution appears to have taken place, the figured and named horses are probably only the extreme ends of little series.

Yet the story is complete in that we have seen the development in the Tertiary of true horses from little creatures the size of terriers.

The story of the horse is an illustration of the adaptation for speed, with consequent reduction of the toes and lengthening of the legs, but as the neck was always long enough for the animal to browse or graze all was well.

In the history of the elephants, so far as it is reconstructed (fig. 78), we see a different condition. The legs increase in length and the animal increases in body size, but other changes have to take place to compensate the animal.

The first member of the series is *Moeritherium* which, like some other interesting Eocene animals, was found in the Fayum, Egypt. It was a small mammal about two feet high and was normally toothed but had large incisors; in the next (Oligocene) period it was succeeded by *Palaeomastodon*, though for a time the two animals lived side by side.

Palaeomastodon had a larger skull and a bigger body, perhaps about four feet high, but it had a number of interesting features in its skull. The upper and lower jaws had the incisors formed into strong digging tusks. The lower tusks are horizontal and the upper ones point downwards. They were clearly adapted for digging. Because of the lengthening of the jaws the nostril opening appears to be placed far back on the skull, and it is probable that the upper jaw was clothed with the beginnings of a long, fleshy upper lip or primitive trunk.

Derived from *Palaeomastodon* was the Miocene form, *Trilophodon*, whose name refers to the three-ridged grinders. It is perhaps now more often referred to as *Gomphotherium*. This was a large animal, probably the size of a small Indian elephant of today. Its tusks were correspondingly large, and those of the lower jaw were

Fig. 79 THE SOUTH AMERICAN GIANT SLOTH, MEGATHERIUM
About twelve feet high

spade-like and protruded, with part of the lower jaw, for quite a long way. Without a trunk this animal would probably have been doomed to starvation, for all it would have got to eat or drink would have had to be shovelled up with the tusks and spout-like jaw and tipped back to the mouth. Even with a trunk this primitive elephant was not quite adapted to its habitat as compared with the modern elephants, for the short trunk must have been supported by the extraordinary lower-jaw scoop. The teeth by now had a number of cusps and several transverse ridges.

During the subsequent periods there are several divergent lines, distinguished by size, the characters of the tusks and the nature of the grinding teeth. Amongst these are the *Mastodon* and *Rhynchotherium* (*Dibelodon*) which became extinct in the Upper Pliocene of North America, but the main line was continued in *Stegodon* which has low-crowned grinding teeth with many transverse ridges. In the *Stegodon* group the lower tusks have disappeared and with them has gone much of the extension of the lower jaw. The trunk could therefore hang free and be moved in any direction that was desired.

From somewhere in this last group came the Woolly Mammoth (fig. 80), and the surviving elephants, the Indian and the African.

The story usually told on these lines is too simple. Recent studies by Professor Henry Fairfield Osborn, published in two magnificent volumes, show that there were no less than three hundred and thirty extinct species of elephants, in the widest sense of that term. Only two elephants survive. This great group appears to have arisen, perhaps in the late Cretaceous, in South Africa, and it spread north and eastwards to Europe, Asia and the Americas.

It is thus a story with many sidelines, but again it is a case of growth of limbs, alteration of dental structure and arrangement; in this case there is also the saving grace of a new structure, the trunk, which enabled the animal to drink and feed when the heavy skull, on the strong but short neck, could no longer reach the ground.

These two great groups that are well known to us illustrate some evolutionary principles which can be seen in many other groups known only from their fossil remains.

One of these is the constant tendency for forms in many groups to assume a larger size. We have seen this in the invertebrates, and besides growth of body, we have seen in the fish, amphibia, reptiles and mammals, growth of limb, specialization in teeth, but, generally, still the same small brain.

It has been held by some that this increase is an advance; the bigger the animal the better it can defend itself, the more important it is. (Even in the human field, a man who throws his weight about may be considered important.) Yet is this true? The mighty dinosaurs were a mighty nuisance to themselves. As mechanisms they were magnificent, but what complex adjustments had to be made!

It used to be said, as a joke, about a certain cheap motor car that if you spent another hundred pounds or so on gadgets it was almost as good as a real motor car. What gadgets the sauropod dinosaurs devised! Light bones and heavy bones, and an additional 'brain' in the sacrum. Finally they had to take to the water to buoy up their weight. Even if they had gone to the water before their weight ran away with them, the resultant highly adapted form was

Fig. 80 THE WOOLLY MAMMOTH

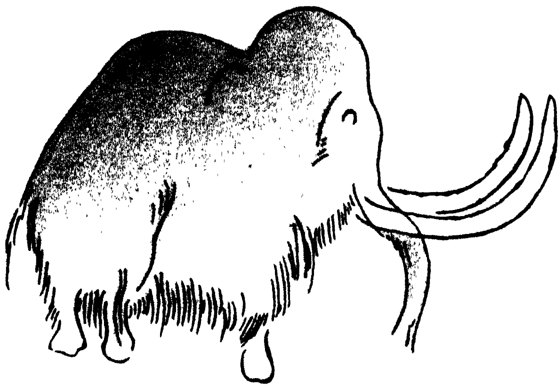


Fig. 81 A CAVE DRAWING OF THE MAMMOTH

suited for one medium only, and if that changed, as indeed it did, there was no future for them.

The armoured dinosaurs were pretty much the same. The vaunted armour, so useful in classification for the palaeontologist, was of less value to them. Great plates of bone in unimportant places, like the backbone plates of the Stegosaurs, were no real protection from the contemporary carnivores. The grotesque bone-headedness of a bipedal dinosaur, *Pachycephalosaurus* (fig. 82), was no real protection for his tiny brain. Any self-respecting Theropod could bite his head off!

The early mammals, and even some of the later ones, went through the same performance. *Megatherium*, the giant sloth, was a prey for animals that might not have worried him if he had stayed smaller and kept to the trees. The extraordinary horned *Syntheto-ceras* of the Pliocene (fig. 83) had horns above his eyes, which might have been a protection from the branches of trees, but he capped all this by a monstrous pick-axe affair, nearly three feet long, upon his nose. This was not offensive or defensive armour, it was a nuisance.

Among the latest mammals, the Woolly Mammoth that was seen and pictured by men (fig. 81) was especially suited to the

Fig. 82 PACHYCEPHALOSAURUS
A remarkably bone-headed dinosaur

rigours of the arctic, but changed conditions altered all that and it became extinct. The great *Diprotodon* (fig. 84), a marsupial giant, fell, too, in an evolutionary byway. Many forms died, of course, through the actions of men, and one such instance concerns a bird, for a change, which was large and comfortable and eminently suited to the peace and quiet of Mauritius, but men came and it was exterminated in the seventeenth century (fig. 85).

The problem posed by all these is the problem of Hamlet. 'To be or not to be' — specialized? And to this the answer was provided by an outside force. The bony development, the tooth changes, are direct responses to environment in the shape of activity of the ectoderm of the animal. The increase in size is a glandular (pituitary) business. As with the development of shells in invertebrates it is in a way probably pathological. Some day someone may be able to write the metabolic formula that tends to produce this development in various media. The hormones appear to get tired of doing nothing and rush off to elaborate the outside of a skull that really needs elaborating in another way within. So the animal becomes over specialized, and when changes come, it cannot change, for if one thing is certain about evolution, it is that it is not reversible.

Changes of food and climate killed more specialized animals than all the carnivores ever did, for they killed whole races.

The animals are not to blame, for they were the victims of a power they could not know. As Burns says in his own epitaph, 'thoughtless follies laid him low and stained his name'. So were brought down the giants of the past.

If we look at the other side of the evolutionary picture, we see something even more remarkable.

It is that all the great evolutionary steps came from simple, unobtrusive animals or groups that, once they had given birth, faded away. And these births, from fish to tetrapod, amphibian to reptile, reptile to mammal, and ape to man, always came at the right time. The world was at those moments always 'waiting for the sunrise' and the sunrise came. Further, these steps were not just the successful results of many tries, they were perhaps the only ones.

Fig. 83 SYNTHETOCERAS
A ruminant with unusual horns

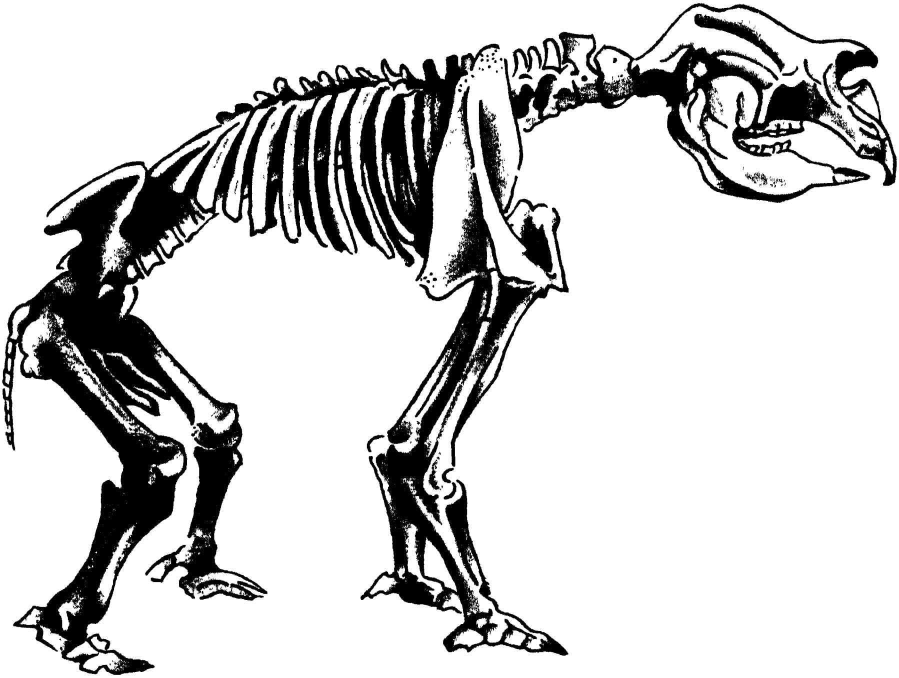


Fig. 84 DIPROTODON
The largest known Australian marsupial

If the physiological factors that determine extinction are peculiar how much more peculiar is the inhibiting factor, the unknown power that says 'thou shalt not specialize'. The little commonplace form grows bigger in its brain, not in its body, and it does not adorn itself for the great day but just awaits the call.

Dr. Robert Broom has pointed out that none of these great evolutionary steps could ever take place again. Unless life is destroyed on earth and a new start made, spectacular evolution on the previous lines is finished and the future lies largely with Man.

According to Sir James Jeans the earth may last for ten thousand million years yet before it and all its life are dead, so Man has more time at his disposal than ever the dinosaurs had. But he has gifts

much more important than time that these monumental failures of the past never possessed. He has consciousness and speech.

The animals have instinct and their own individual experience. We have instinct and the experience of all mankind at our disposal, if only we wish to make use of it.

Fig. 85 THE DODO
A flightless bird that was exterminated by man in the seventeenth century

We need not despise these failures of the past; they were builders as we are. Longfellow says

> All are architects of Fate
> Working in these Walls of Time.

We are instructed architects; the plans are in our hands, the future is in large measure at our command. There is perhaps only one thing we should learn from the study of these creatures of the past. They lived and preyed; they fought and devoured each other; but in the whole long history of invertebrate and vertebrate life there is no group that planned deliberately, or even attempted casually, to end the race to which it happened to belong.

Thus, given goodwill and all our knowledge, what advances we could make in the time that lies before us. The Corridor of Life from the past might well lead to new high levels of living in the future, to the demolition of poverty and the conquest of disease; to the building of happier mansions for a fuller and a freer life for all; where men might develop untried standards of peace and co-operation.

This demands no major climatic change, no new evolutionary stimulus, it just depends *on us*. May we therefore determine to be as good architects in our turn as were the great animal architects of the past.

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